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LIMITATIONS OF GROUND WATER AS AID IN DETERMINATION OF HIDDEN GEOLOGIC STRUCTURE[1]

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ABSTRACT

The main features of the water table are controlled by the topography. The usefulness of water-table data in searching for buried structure is limited, therefore, to those localities where the surface of the land is relatively flat; consequently, where there is no topographic clue to the underlying structure. Under such conditions, irregularities of the water table such as wide flat terraces, sharply defined artesian areas, or anticlinal bulges may be reliable indicators of the existence and location of buried structure. In making hydrographic contour maps, water levels on piezometric surfaces are sometimes erroneously included with the water-table levels, producing misleading results. Many small but prominent water-table irregularities are the result of local variation in porosity of the water-bearing material, whereas other similar irregularities are due to artificial causes such as intensive pumping of wells or extensive irrigation of some areas. There are large areas in California, on the Gulf Coastal Plain, and along the Atlantic Coastal Plain where carefully compiled ground-water data may prove helpful in determining hidden geologic structure when used with the proper limitations.

INTRODUCTION

It is generally recognized that certain geologic structural features which may be present in an area, although indistinct or hidden at the surface, will profoundly affect the ground-water relations within the area. Reference to this fact, with specific examples, may be found in many of the Water-Supply Papers of the United States Geological Survey, in state reports, and in engineers' reports on water supply. For

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several years, geologists, especially in California, have used ground-water data in the search for structures which might contain oil. Not a few wells have been located chiefly or entirely on the basis of such data. Nearly every such well, so far as known to the writer, has failed to develop commercial amounts of oil, and the inference is that the favorable structure suggested by the ground-water relations was not present. This seeming failure of ground-water data as a reliable aid in the determination of hidden, or buried, structure has been the cause of considerable speculation. In this paper the writer presents his conclusions derived from a study of ground-water conditions in southern California with special reference to certain localities where the subsurface structure is known to have affected the ground-water movement.

UNDERGROUND WATER ZONES

Unsaturated zone.—Water which percolates downward at times of rainfall through the soil, alluvium, or porous rock near the surface, eventually reaches a level below which the rock is saturated with water. The zone between the top of this saturated zone and the surface of the ground is known as the *unsaturated zone*,[1] or *zone of aeration*.[2] In this zone the direction of movement of the underground water is essentially vertically downward during times of rainfall and vertically upward by capillary action during dry periods.

Upper zone of saturation.—The zone extending from the top of the first saturated zone downward to the top of the first impervious material *of general extent* is called the *upper zone of saturation*, or *upper zone of flow*.[3]

Lower zone, or zones, of saturation.—All saturated zones below the first impervious material of general extent are considered to be in the *lower zone of saturation*, or *lower zone of flow*.[4] There may be several lower zones of saturation. They are not dependent on local rainfall; many receive their waters from distant areas. The pervious water-carrying strata in the lower zone, or zones, of saturation are overlain and underlain by relatively impervious beds; thus, they differ markedly from the upper zone of saturation which has an unconfined, free upper boundary. As the water-carrying strata in the lower zones of saturation

[1]Charles S. Slichter, "Motions of Underground Waters," *U. S. Geol. Survey Water-Supply Paper 67* (1902), p. 32.

[2]Oscar Edw. Meinzer, "The Occurrence of Ground Water in the United States," *U. S. Geol. Survey Water-Supply Paper 489* (1923), p. 29.

[3]Charles S. Slichter, *op. cit.*, p. 32.

[4]*Idem.*

are confined between impervious beds, the waters contained in such porous strata are generally under artesian (hydrostatic) pressure. Because of this, the movement of the underground waters in the lower zones of saturation is ordinarily independent of the surface topography and drainage and is largely controlled by regional geologic structure, whereas the movement of underground waters in the upper zone of saturation is largely controlled by the surface topography.

Most water-bearing strata encountered in ordinary water wells are in the upper zone of saturation. Most water-bearing strata encountered in oil wells and in the deeper water wells lie in the lower zone of saturation.

GROUND WATER DEFINED

The term *ground water* is used to designate the subsurface water within the upper and lower zones of saturation. Water occupying the unsaturated zone (zone of aeration) is not included within the meaning of the term.[1]

AQUIFERS

According to Meinzer's[2] definition, "an aquifer is a formation, group of formations, or part of a formation that is water-bearing." Other terms in common use synonymous with aquifer are *water-bearing bed*, *water-bearing stratum*, and *ground-water reservoir*. The terms are generally restricted to formations or strata which will yield water in sufficient quantity to constitute a source of supply.

Artesian aquifers.—If the static level of the ground water in an aquifer is above the upper surface of the upper zone of saturation, it is said to be under *artesian pressure*, or *artesian head*. An artesian aquifer is one in which the water is under artesian pressure.[3]

WATER TABLE

The water table is the upper surface of the upper zone of saturation. As no water table exists where the upper surface of a zone of saturation is formed by an impervious stratum,[4] there can be no water table in the lower zone or zones of saturation, where all aquifers are confined between impervious layers.

[1] Oscar Edw. Meinzer, *op. cit.*, p. 38.

[2] *Idem*, "Outline of Ground-Water Hydrology," *U. S. Geol. Survey Water-Supply Paper 494* (1923), p. 30.

[3] *Idem*, p. 39.

[4] *Idem*, p. 22.

Perched water tables.—Where an upper body of ground water is separated by unsaturated rock from the main body of ground water which lies below the unsaturated rock but within the upper zone of saturation, the ground water above the unsaturated material is said to be "perched," and its water table is a *perched water table*. Perched water is due to the presence of local impervious strata, as lenticular clay beds, or lenticular masses of tightly cemented sands, above the main water table. Perched water tables are sometimes confused with conditions resulting from the penetration of artesian aquifers in wells in which the water rises considerably above the water table.

PIEZOMETRIC SURFACES

A piezometric surface of an aquifer is "an imaginary surface that everywhere coincides with the static level of the water in the aquifer. It is the surface to which the water from a given aquifer will rise under full head."[1]

It is important to distinguish clearly between piezometric surfaces and water tables because the two are sometimes confused by petroleum geologists. It is probable that some of the disappointing results obtained from the use of ground-water data in oil exploration are due to the failure to distinguish between the different conditions represented by water tables, perched water tables, and piezometric surfaces.

When a well penetrates an aquifer in the upper zone of saturation, water enters the hole, but in few holes rises much above the level of the water table, because the upper surface of this zone is free and unconfined. But when a well penetrates an aquifer in the lower zone of saturation, wherein all aquifers are confined between upper and lower impervious boundaries, the water nearly always rises in the hole some distance above the level of the top of the aquifer, because of the artesian pressure which generally exists in such aquifers. The level to which the water rises in the well depends on the degree of hydrostatic pressure existing at the locality. It may rise only a few feet, it may rise to the water-table level, or above the water-table level, or it may rise to the ground surface or even above the ground surface. Under the last two conditions, an artesian well results. Under any condition, except the rare one where by mere coincidence the water from such a confined aquifer rises exactly to the level of the water table, two different water levels result in two adjacent wells, one of which taps a shallow aquifer in the upper zone of saturation and the other an artesian aquifer in the lower zone of saturation. In the first situation, the water level in the well represents the water

[1]Oscar Edw. Meinzer, *op. cit.*, p. 38.

table; in the second, the water level in the well represents the piezometric surface.

In many places, several confined aquifers are present, one above the other and separated by impervious shales or other material. If the hydrostatic pressure varies in the different aquifers, there is a corresponding number of different piezometric surfaces and all may be different from the water table of the area. If a body of perched water is present in the area, there is still another ground-water level to complicate the situation further.

METHOD OF MAPPING WATER TABLE

The method generally used in mapping the water table is to collect all the available data regarding the standing-water levels in the domestic water wells in the area under investigation. The measurements of the water levels in the various wells should be made in as short a time as possible and in any well certainly during a single season. This is necessitated by the rapid changes which occur in the ground-water levels of an area with changes of season and the increased or diminished water supply which accompanies the seasonal change. The changes of level of the water table are especially conspicuous in a semi-arid climate such as prevails in southern California.

The depths to the top of the standing water in the wells are converted to elevations above or below sea-level, for each well. The well locations having been plotted as accurately as possible on a map, the water-table elevations are marked on the map at the proper locations, and contours are drawn through points of equal elevation on the water table. The resulting contour map, called a hydrographic or ground-water contour map, shows the shape of the water table as of the date on which the well measurements were made. The accuracy of such a map, on the assumption that there were no errors in technique, depends chiefly on the number and distribution of the wells measured. If a topographic map is available, it should be used as a base for the ground-water map.

When all the water-table elevations obtained by measurements of wells are plotted on the map ready for contouring, some erratic wells with abnormally high or low water-table levels are noticed. These should be examined carefully to determine, if possible, the cause of the seeming discrepancy. For this study, it is essential to know the depths of the different wells, and especially the depths, and corresponding elevations, of the principal aquifers tapped by the wells. It is found almost without exception that abnormally high water levels in separated wells occur only in the deeper wells of the region which have penetrated aquifers in

which the water is under artesian pressure. Hence, the high water levels in such wells do not represent the water table, but represent the piezometric surfaces of artesian aquifers. In some areas, all the wells of a group of closely spaced deep water wells, from which large quantities of water are pumped by some water company or municipality, show abnormally low water levels, but these levels are approximately the same within the wells of the group. All wells in which it is evident or probable that abnormally high water levels represent piezometric surfaces should be excluded when the ground-water contours are drawn. To include them would result in a totally erroneous picture of the water table. It is probable that several of the "ground-water highs" which have been drilled for oil in the belief or hope that they might be caused by buried hills or domes below, in reality were not water-table "highs," but only false "highs" on the map, due to the inclusion of points on some piezometric surface when the contours were drawn.

Where separated wells of average depth show abnormally low water levels, the cause is ordinarily intense pumping of such wells, which results in a conspicuous, but local, lowering of the water table. The hydrographic contours should be drawn in a somewhat generalized manner in the vicinity of the artificially depressed areas if a picture of the original or natural water table is desired.

Some deep wells show water levels considerably below the average elevation of the surrounding water table. This condition results when a well produces water from a confined aquifer in the lower zone of saturation in which the hydrostatic pressure is insufficient to raise the water to the level of the water table. Such a condition is known as "sub-normal pressure head."

The water-table elevations used in preparing the accompanying illustrations of areas in the Los Angeles basin were taken from United States Geological Survey Water-Supply Papers 137, 138, and 139 by W. C. Mendenhall.[1] The hydrographic contour maps accompanying these reports were prepared with contour intervals of 10 and 20 feet. The writer has redrawn the hydrographic contours, using a 5-foot contour interval wherever sufficient well data were available, in order to show the shape of the water table in more detail. If measurements of the water levels in the same wells were made now (1931) and new ground-

[1]Walter C. Mendenhall, (1) "Development of Underground Waters in the Eastern Coastal Plain Region of Southern California," (2) "Development of Underground Waters in the Central Coastal Plain Region of Southern California," (3) "Development of Underground Waters in the Western Coastal Plain Region of Southern California," *U. S. Geol. Survey Water-Supply Papers 137, 138*, and *139* (1905).

water contour maps prepared from the new measurements, the maps would look very different from those contained in the original reports because the water table has actually changed both as to elevation and shape. Intensive pumping of water wells and extensive irrigation of lands throughout the Los Angeles basin and adjacent valleys during the past 25 years or more have artificially depressed and distorted the water table in those areas to such an extent that it is doubtful whether the water table *as it exists to-day* would be of any assistance in the search for buried topography and hidden geologic structure.

However, maps showing the water table as it existed 25 years ago should give an accurate picture of the natural ground-water conditions, because then most of the water wells were shallow and bottomed in the upper zone of saturation. Furthermore, artificial distortion of the water table due to heavy pumping was of infrequent occurrence 25 years ago. Under conditions described in the following pages, such ground-water contour maps should reflect the geologic structure of the underlying rocks, and particularly buried hills and ridges. If the topography of a region is largely controlled by the geologic structure, as it is in southern California, any new data which may give a clue to the existence of buried topography will be useful to the geologist in determining geologic structure.

SHAPE OF WATER TABLE

EFFECT OF TOPOGRAPHY ON WATER TABLE

The surface topography ordinarily controls the form and position of the water table, but topography has no appreciable effect on the ground-water levels in the lower zones of saturation, where the water is under hydrostatic pressure in aquifers confined between upper and lower impervious boundaries. The shape of the water table is generally approximately parallel with the slope of the land surface, but nearly everywhere less steep than the surface slope. Consequently, the surface water-shed ordinarily coincides with the underground water divide, and the direction of flow of the ground water in the upper zone of saturation is ordinarily parallel with the surface run-off into the streams.[1] Most conspicuous exceptions to this rule are caused by some structural feature, such as the Monk Hill "dike"[2] in North Pasadena, which forms a subsurface rock dam and diverts the underground flow from its natural

[1]Charles S. Slichter, *op. cit.*, p. 32.

[2]W. C. Mendenhall, "Ground Waters and Irrigation Enterprises in the Foothill Belt, Southern California," *U. S. Geol. Survey Water-Supply Paper 219* (1908), p. 52.

course parallel with the surface drainage, and causes it to turn eastward around the end of the barrier. The ground waters are thus diverted from the Los Angeles River drainage basin and forced into the San Gabriel River drainage basin.

If the porous and less consolidated material which holds the ground water in the upper zone of saturation covers the hills as well as the valleys, the water table rises in the hills, and sags in the valleys, thus having an undulating shape with ridges and valleys corresponding with the surface topography. Beneath a low ridge or an elongate hill covered with porous water-bearing material the ground-water contours appear as a gentle anticline or elongate dome. This condition is admirably illustrated in the Torrance and Santa Fe Springs oil fields in the Los Angeles basin of California (Figs. 1 and 2). At both localities the anticlinal structure is suggested in the surface topography by long, low, gently sloping

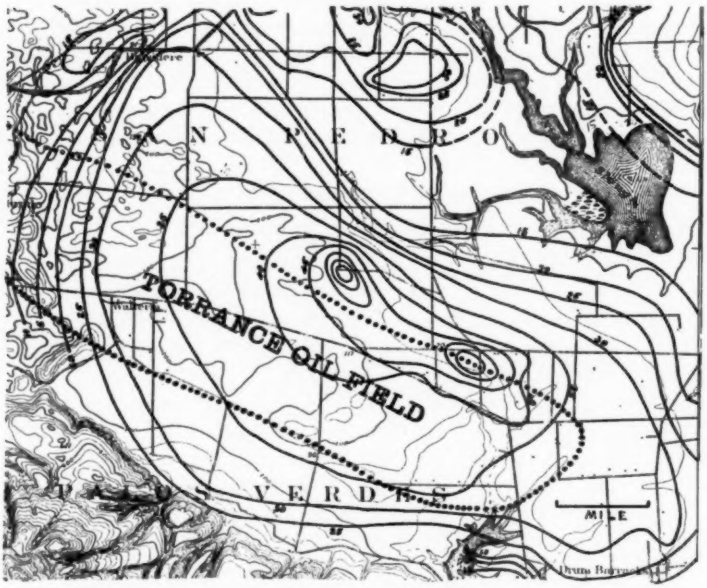

Fig. 1.—Torrance Oil field, Los Angeles basin, California, showing ground-water contours and relation of 1904 water table to topography and to productive area of field. (Ground-water data from *U. S. Geol. Survey Water-Supply Paper 139;* contour interval, 5 feet. Topographic base: *U. S. Geol. Survey Redondo Quadrangle;* contour interval, 25 feet.)

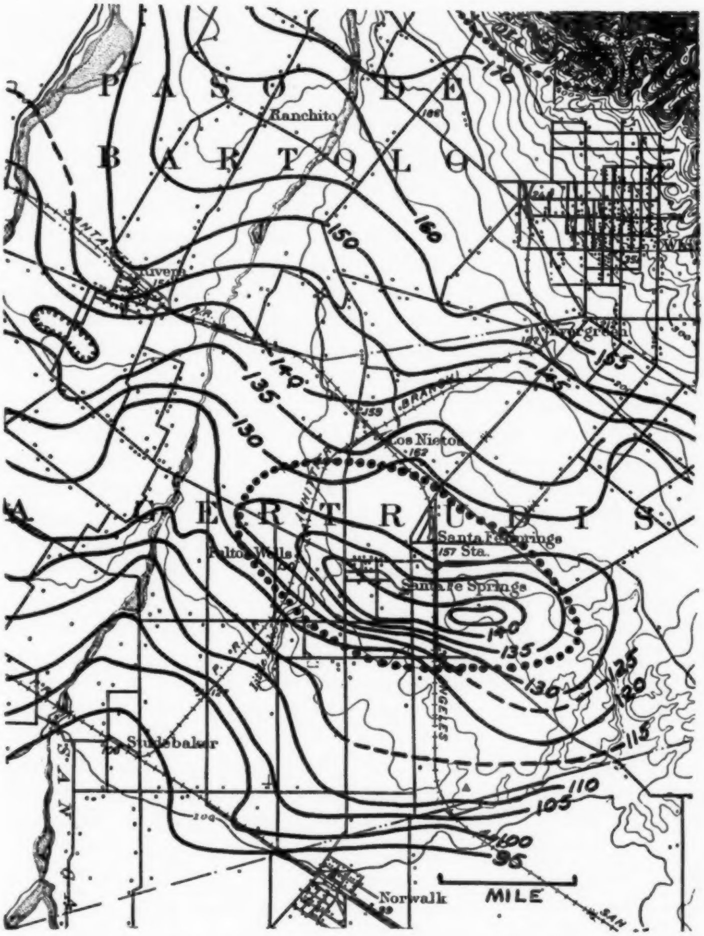

FIG. 2.—Santa Fe Springs oil field, Los Angeles basin, California, showing ground-water contours and relation of 1904 water table to topography and to productive area of field. (Ground-water data from *U. S. Geol. Survey Water-Supply Paper 138;* contour interval, 5 feet. Topographic base: *U. S. Geol. Survey Downey Quadrangle;* contour interval, 25 feet.)

ridges, or a series of very low hills of alluvium alignment. These topographic features, covered with considerable poorly consolidated water-bearing material of Pleistocene and Recent age, have caused pronounced anticlinal bulges on the water table. The highest parts of the water-table bulges at the two localities correspond closely, but not exactly, with the highest areas of the land surface. Many geologists have pointed to the water-table features at Torrance as convincing proof of the reliability of ground-water data as an aid in mapping geologic structure. As a matter of fact, the "water-table anticlines" at Torrance and Santa Fe Springs do happen to indicate very accurately the character of the underlying structure, but that is chiefly because the anticlinal uplift has produced certain topographic features which in turn produced the ground-water features. If erosion had kept pace with structural deformation, and if the surface of the land at these localities was thus worn flat, it is doubtful whether these prominent anticlinal features of the water table would exist. If the erosion of the crests of the folds at Torrance and Santa Fe Springs had removed all or most of the porous water-bearing material of the upper zone of saturation, a subsurface barrier of relatively impervious material such as the older and denser Pleistocene formations would have been left across the course of the seaward-moving ground water. Such a barrier would be structural rather than topographic and would have an effect on the water table quite different from the existing one. The water-table level would rise *behind* the barrier, as a reservoir rises behind a dam, instead of directly over it. Moreover, the ground waters would probably rise evenly over a considerable area behind the barrier, causing a water-table terrace or an artesian area instead of an anticlinal bulge.

Other conspicuous examples of anticlinal bulges of the water table coinciding with low topographic ridges, to which the ground-water features are due, are to be seen along Buttonwillow Ridge and Semitropic Ridge in the San Joaquin Valley[1] (Fig. 3). At these localities low topographic swells exist which are so gentle in slope as to escape the eye of the casual observer. Ground-water contour maps show conspicuous anticlinal bulges of the water table along the axes of the ridges. The positions of the water-table features coincide exactly with the topography because there is no ground-water barrier present. The ridges may be anticlinal in structure but the water-table features would exist as they are regardless of the underlying structure.

[1] *State of California Dept. of Engineering Bull. 9* (1920). Also *State of California Dept. of Public Works, Divisions of Engineering and Irrigation and of Water Rights Bull. 11* (1927).

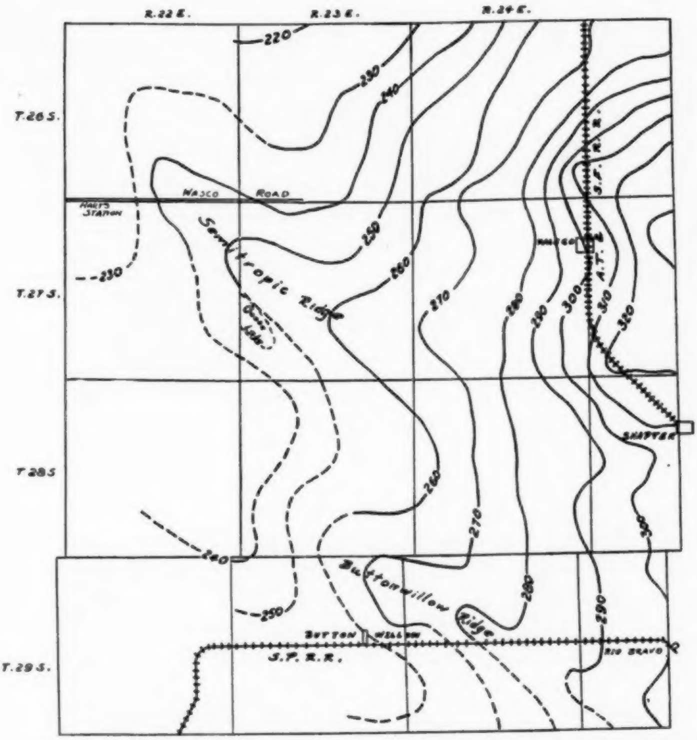

FIG. 3.—Ground-water contour map showing shape of water table along Buttonwillow and Semitropic ridges, San Joaquin Valley, California. Notice "ridges" on water table. (Data from *Bull. 9, Div. of Engineering, Dept. of Public Works, State of California*. Contour interval, 10 feet.) Scale: 1 township, approximately 6 miles wide.

If hills and ridges are composed of relatively impervious rock from which the porous water-holding material has been eroded, or upon which it was never deposited, the water table is not undulating. Under such conditions, the hill or ridge acts as a structural barrier. The ground water, moving seaward below the plain or valley, encounters the barrier and is ponded against it, on the "up-stream" side of the hill, as surface water is held against a dam. This ponding or damming of the ground water causes the water table to rise toward the surface. If the barrier is absolute, and if the quantity of ground water is large, the water table

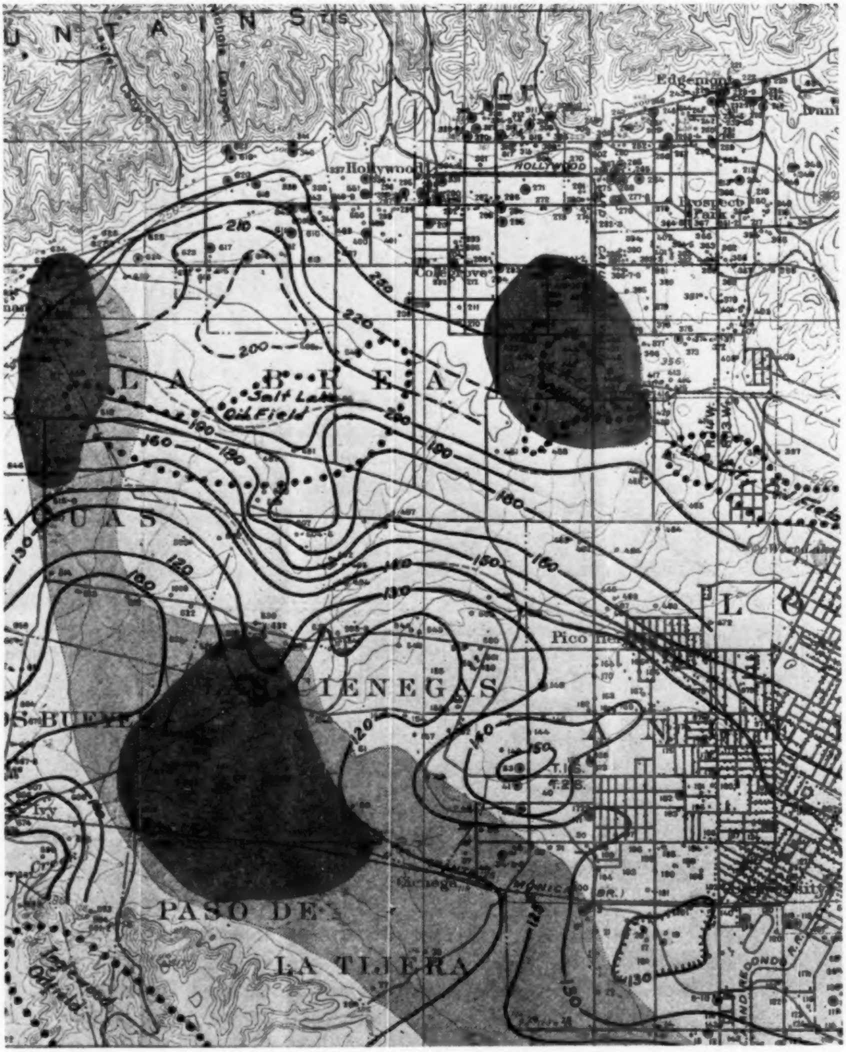

FIG. 4.—Salt Lake oil field and part of Los Angeles oil field, Los Angeles basin, California, showing ground-water contours, water table of 1904, and original artesian areas. Notice relation of water-table features to topography and to productive area of Salt Lake field. (Ground-water data from *U. S. Geol. Survey Water-Supply Paper 139;* contour interval, 10 feet. Topographic base: *U. S. Geol. Survey Santa Monica Quadrangle;* contour interval, 50 feet.) Light shading: approximate original artesian area. Dark: artesian areas of 1904. Heavy dotted lines indicate oil-field boundaries. Heavy full lines show ground-water contours. Width of area mapped, approximately 6.5 miles.

eventually rises to the level of the ground and an artesian area, or marsh, is produced. This is clearly illustrated by the original artesian areas of the Los Angeles basin[1] (Fig. 4).

If the topographic and geologic barrier is not absolute, or if the supply of ground water is insufficient completely to fill the porous zone to the ground surface, the effect of the barrier is to raise the water table to some level below the ground surface but notably higher than the level existing on the lower side of the barrier. The water table above the barrier may resemble a gently sloping plane, it may exhibit a wide flat terrace, or it may be somewhat irregular in shape, with an anticlinal bulge adjacent to the barrier. Under these conditions, the water-table "high" would not overlie the structural barrier, but would be behind the barrier and adjacent to it.

An interesting and exceptional illustration of the effect of combined topographic and geologic barriers in producing a prominent anticlinal bulge of the water table may be seen at La Habra in the Los Angeles basin (Fig. 5). At this locality there is a narrow valley trending east and

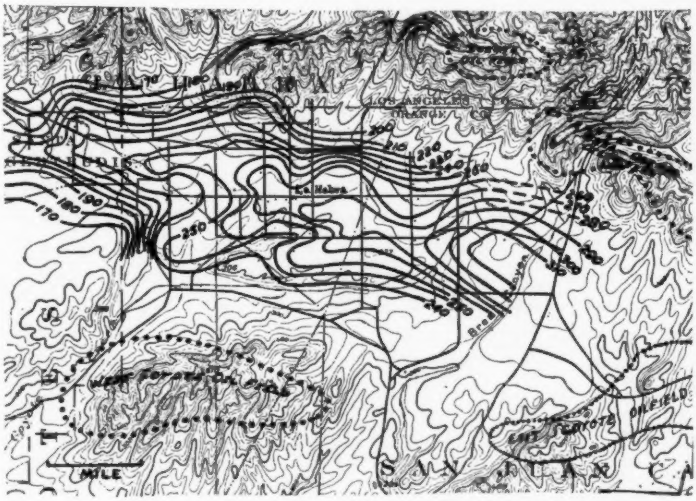

FIG. 5.—La Habra area, Orange County, California, showing ground-water contours and shape of water table as of 1904. Notice "anticlinal" feature of water table along La Habra Valley. (Ground-water data from *U. S. Geol. Survey Water-Supply Paper 137;* contour interval, 10 feet. Topographic base: *U. S. Geol. Survey Anaheim Quadrangle;* contour interval, 25 feet.)

[1]W. C. Mendenhall, *op. cit.*

west between two parallel ridges, the Puente Hills on the north, and the Coyote Hills on the south. The surface formations on these hills consist of soft shales and clayey sandstones, considerably weathered. The lower slopes are deeply soil-covered and are capable of holding considerable ground water. The ground waters, following the general lines of the surface drainage, move northward down the north slopes of the Coyote Hills, and southward down the south slopes of the Puente Hills. The waters from the north and south mingle in the narrow valley between the ridges, where they rise toward the surface under hydrostatic pressure, forming a narrow but prominent anticlinal bulge on the water table, the axis of which extends along the trough of the valley. Were it not for the fact that the ground waters can escape toward the sea around the east and west ends of the Coyote Hills, the water table in La Habra Valley would probably be at the ground surface. This "anticlinal" feature of the water table along the trough of a synclinal valley illustrates the danger in assuming that water-table "highs" indicate buried structure without carefully studying the known topographic and structural features of the surrounding area.

The most important clues relating to the cause of a given water-table "high" are to be had from (1) its position with respect to the surrounding topography, and (2) the shape of the water-table feature. If the surface of the land is flat, any prominent ground-water irregularity must be due to subsurface conditions, and probably reflects some structural feature.

Certain topographic features produce special types of irregularity in the shape of the water table. Among these may be noted the effects produced by (1) alluvial fans, and (2) natural levees, or channel ridges, along streams. The water table beneath alluvial fans is ordinarily similar to the surface of the fan in shape. This is well illustrated by certain water-table features along the southern end of the east side of the San Joaquin Valley,[1] California[2] (Fig. 6). On a ground-water contour map, the water table beneath an alluvial fan has the shape of a broad anticlinal nose. When the ground-water contours are superposed on the surface contours, the relation of the water-table feature to the topography is obvious.

[1]Mendenhall, Dole, and Stabler, "Ground Water in San Joaquin Valley, California," *U. S. Geol. Survey Water-Supply Paper 398* (1916).

[2]"Water Resources of Kern River and Adjacent Streams," *State of California Dept. of Engineering Bull. 9* (1920). Also, "Ground Water Resources of the Southern San Joaquin Valley," *State of California Dept. of Public Works, Divisions of Engineering and Irrigation and of Water Rights Bull. 11* (1927).

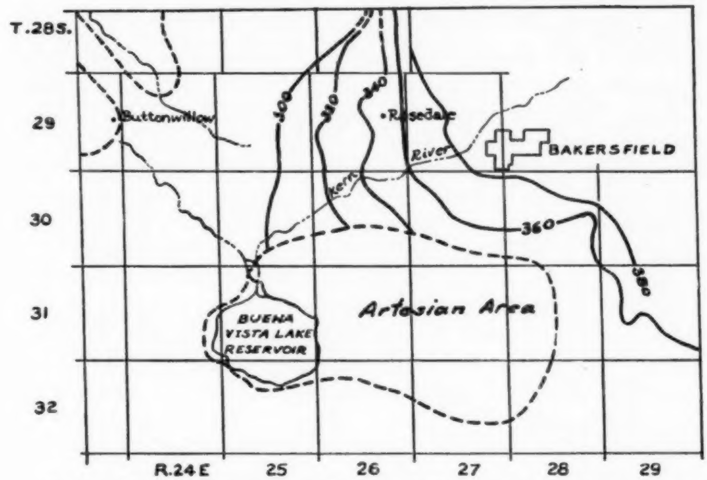

FIG. 6.—Bakersfield area, Kern County, California, showing shape of water table on alluvial fan at mouth of Kern River. Notice similarity between shape of water table and typical fan topography. (After Mendenhall, Dole, and Stabler, *U. S. Geol. Survey Water-Supply Paper 398;* ground-water contour interval, 20 feet.) Scale: 1 township, approximately 6 miles wide.

Natural levees, or channel ridges, are low topographic ridges which border some stream courses across relatively wide, flat valleys. These ridges are built up by the deposition of sand, mud, and silt near the sides of the channel during periods of high water and overflow. On the west side of the Sacramento Valley in northern California, especially between Willows and the Montezuma Hills, typical channel ridges have been built by the intermittent streams that flow from the hills on the west to join Sacramento River.[1] These channel ridges vary in height from 3 to 20 feet. Their slopes are ordinarily so gradual that it is difficult to detect them in the field. Because of the very porous nature of the material composing the channel ridges, they become saturated with ground water, the water table of which takes the general shape of the ridges. Ground-water contour maps of the area thus show peculiar narrow anticlinal bulges of the water table, the origin of which at first might be puzzling, but becomes evident when the ground-water contours are superposed on an accurate topographic map.

[1]Kirk Bryan, "Geology and Ground Water Resources of Sacramento Valley, California," *U. S. Geol. Survey Water-Supply Paper 495* (1923), pp. 28 and 83.

EFFECTS OF GEOLOGIC STRUCTURE ON WATER TABLE

Buried hills and ridges.—Most known examples of water-table irregularities which are entirely caused by hidden underlying geologic structure involve old buried topography. Examples of hills and ridges, worn down by erosion and buried beneath alluvium and valley fill, are numerous, especially in coastal-plain areas and in desert basins. If the tops of such buried hills and ridges are not too deep beneath the surface, they may cause important and conspicuous irregularities of the water table such as artesian areas, terrace effects, and anticlinal bulges. If the buried hills represent anticlines, as many of them do, the existence of such anticlines may be detected by the ground-water features. Without drilling there is, of course, no method by which the structure of a buried hill can be definitely determined. A fairly reliable clue may be had from the relation between the topography and structure visible in the surrounding region. A still more reliable clue might be supplied by the alignment of some prominent topographic spur in the hills bordering the plain or valley with the water-table feature in question. In the Los Angeles basin and surrounding region, nearly all topographic hills and ridges are anticlinal. Therefore, it is a justifiable assumption that a buried hill or ridge, indicated by some water-table features, is probably anticlinal.

One example of a buried ridge which affects the water table is the so-called Raymond Hill "dike" in South Pasadena described by Mendenhall[1] and by Johnson and Warren.[2] Extending northeast from Raymond Hill in South Pasadena toward a spur of the San Gabriel Mountains a short distance east of the mouth of Santa Anita Canyon, there is a line marked by a few low topographic irregularities. Near the southwest end of this line there is a very distinct topographic rise, but near the northeast there are places where no topographic evidence exists. The water table above this line (between the line of topographic features and the San Gabriel Range) is high and flat, whereas below the line the water table is deep and steep, as shown in Figure 7. Geological studies supplemented by well logs clearly indicate the presence of a buried ridge along this line, probably the southwestern continuation of the mountain

[1]Walter C. Mendenhall, "Ground Waters and Irrigation Enterprises in the Foothill Belt, Southern California," *U. S. Geol. Survey Water-Supply Paper 219* (1908), p. 50.

[2]Harry R. Johnson and Van Court Warren, "Geological and Structural Conditions of the San Gabriel Valley Region," *State of California Dept. of Public Works, Division of Water Rights Bull. 5* (1927), pp. 73-100.

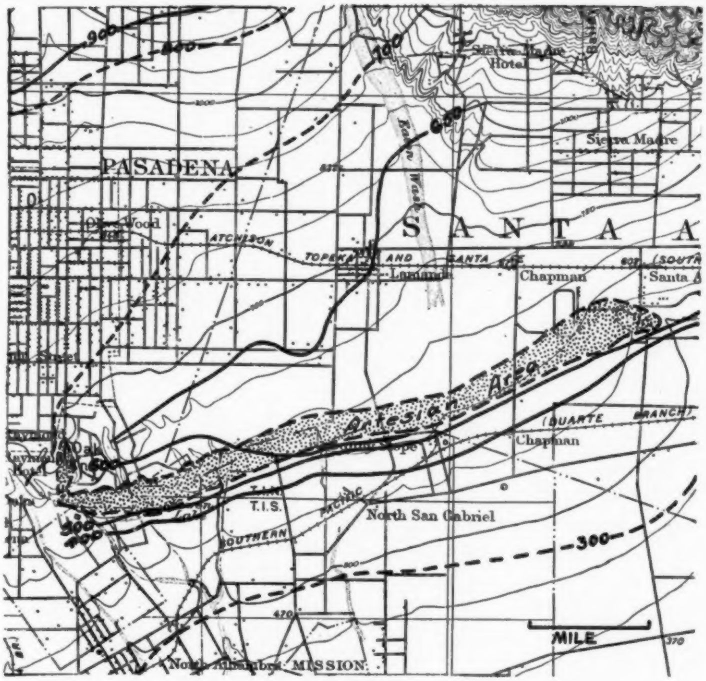

FIG. 7.—Pasadena area, California, showing ground-water contours and shape of water table as of 1904 along buried ridge known as Raymond Hill "dike." (After Mendenhall. Ground-water data from *U. S. Geol. Survey Water-Supply Paper 219.* Topographic base: *U. S. Geol. Survey Pasadena Quadrangle;* contour interval, 50 feet.)

spur already mentioned. This buried ridge forms an effective subsurface dam, ponding the ground waters behind it and causing the features shown in Figure 7. The term "dike" is used by some hydrographic engineers to designate such a subsurface water barrier regardless of its geological structure.

The so-called Monk Hill "dike" in North Pasadena previously mentioned, and described by Mendenhall[1] and by Johnson and Warren,[2] is a buried rock ridge which has produced an effect upon the water table similar to that caused by the Raymond Hill "dike." At the Monk Hill

[1]W. C. Mendenhall, *op. cit.*

[2]H. R. Johnson and Van Court Warren, *op. cit.*

"dike," however, the bed rock crops out at several places and its presence can readily be detected without the aid of ground-water evidence.

Both the Raymond Hill and Monk Hill barriers are partly topographic. The Monk Hill barrier consists of a buried granite spur, whereas the Raymond Hill barrier is a buried anticlinal ridge of Miocene sedimentary rocks. It should be emphasized, however, that in both places the *barrier* is due to the existence of a buried topographic surface. The structure of the buried topography is of secondary importance in so far as it affects the water table.

Other conspicuous examples of important water-table features due to buried topography are those of the area north and northeast of Pomona, shown partly on the topographic map of the Pomona Quadrangle and partly on the Cucamonga Quadrangle. The ground-water conditions in these areas have been mapped and described in detail by Mendenhall.[1] At the eastern extremity of the San Jose Hills, the southward-flowing ground waters are forced to the surface along a zone bordering the north edge of the hills by the topographic barrier formed by the hills, thus causing an extensive artesian area, as shown in Figure 8. The significant feature is the fact that the artesian area extends as a narrow zone across the plain for nearly 2 miles east of the extreme east end of the San Jose Hills, where there is no topographic evidence to indicate what the subsurface conditions may be. Clearly the sharp rise of the water table in this part of the area must be due to some subsurface barrier. The alignment of this artesian zone with the San Jose Hills and its continuity with the artesian area along the north edge of the hills suggests a buried eastward continuation of the hills.

Eroded anticlines.—A small triangular artesian area at the mouth of Ballona Creek, between Del Rey and Santa Monica, and east of the Venice oil field, was described and mapped by Mendenhall[2] in 1905. This artesian area, shown in Figure 9, lies entirely within a tidal marsh along Ballona Slough. As originally mapped, the western boundary of the artesian area formed a remarkably straight line parallel with the coast approximately ¼ mile inland. The coast line at this locality is a low sand bar, and there is no suggestion in the surface topography as to the reason why the ground waters are forced to the surface along such a remarkably straight line.

[1] *Op cit.*, p. 34.

[2] W. C. Mendenhall, "Development of Underground Waters in the Western Coastal Plain Region of Southern California," *U. S. Geol. Survey Water-Supply Paper 139* (1905), p. 15.

FIG. 8.—Map showing ground-water contours and artesian areas as of 1904, north of Pomona, Los Angeles County, California. Notice steep gradient of water table along south edge of larger artesian area. (After Mendenhall. Ground-water data from *U. S. Geol. Survey Water-Supply Paper 219*. Topographic base: *U. S. Geol. Survey Pomona and Cucamonga Quadrangles;* contour interval, 50 feet.)

Developments in the Venice oil field, discovered in 1929 and located between the western edge of the artesian area and the shore, have shown the axis of the producing area to be approximately parallel with the coast. If the Venice structure represents a flexure over a buried schist ridge, as seems probable, involving only a slight warping of the Quaternary sediments, the unconsolidated porous sands and gravels which constitute the water-bearing surface formation of the region at the east may have been eroded from the crest of the flexure, thus exposing the older and less pervious alluvium, or they may not have been deposited along the top of the flexure. The relatively impervious older alluvium, although now covered by recent muds and sands, would form a subsurface dam forcing the ground water to the surface along the line shown on the map (Fig. 9) in much the same manner that the ground water is forced to the

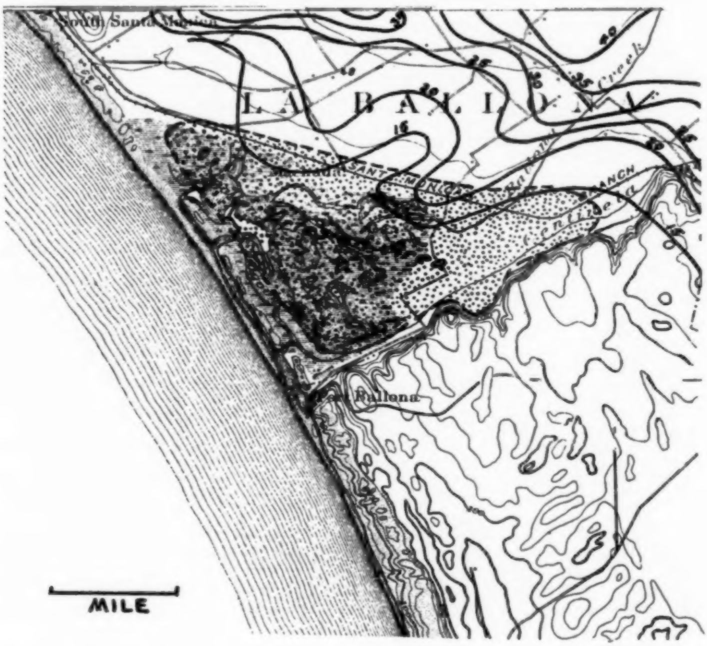

FIG. 9.—Map showing Ballona Slough artesian area as of 1904. Venice oil field lies along coast at western edge of artesian area. (Ground-water data from *U. S. Geol. Survey Water-Supply Paper 139;* contour interval, 5 feet. Topographic base: *U. S. Geol. Survey Redondo Quadrangle;* contour interval, 25 feet.)

surface north of the buried eastward continuation of the San Jose Hills already described (Fig. 8).

Although it may not be possible to demonstrate conclusively, from data now available, that the upper Pleistocene and possibly Recent alluvium were slightly folded along the axis of the Venice oil field, the foregoing explanation of the origin of the Ballona artesian area is offered as being probable. Whether the explanation is entirely correct or not, the fact remains that one well or more located solely on evidence supplied by the water table would have resulted in the discovery of the Venice oil field.

If the amount of erosion along the crest or axis of an anticlinal fold involving the deformation of the water-bearing surface formations is very slight, or if an anticlinal ridge is deeply buried beneath alluvium and valley-fill, the thickness of the water-bearing formations overlying the anticline may be sufficient to permit the ground waters to pass over the fold. In doing so, the water table would be forced upward, as the water table under such conditions would be controlled by the shape of the underlying impervious floor. *Synclines* in the underlying impervious floor have no effect on the water table, but monoclines and anticlines in the impervious floor crossed by moving ground water give a similar form to the water table[1] (Fig. 10). Under such conditions a water-table bulge

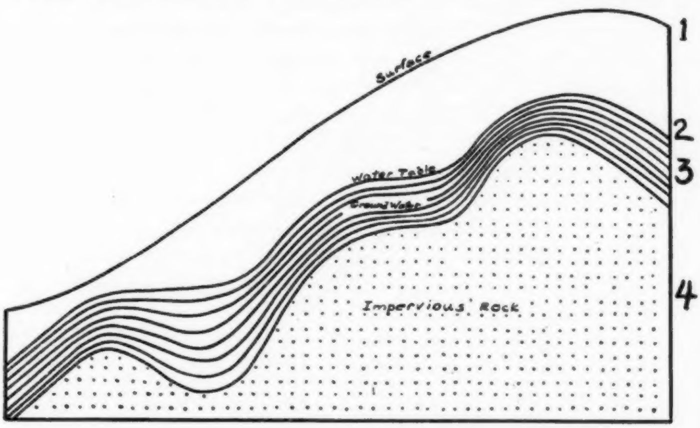

FIG. 10.—Diagram showing effect of impervious rock floor on shape of water table. (After Slichter.) Legend: *1*, surface; *2*, water table; *3*, ground water; *4*, impervious rock.

[1]Charles S. Slichter, *op. cit.*, p. 35.

may be produced directly over the buried structure. This may account for the peculiar and conspicuous water-table features at the old Salt Lake oil field in the city of Los Angeles, shown in Figure 4. At this locality there are no surface topographic features to account for the shape of the water table. The water table presents the combined features of a flat terrace and anticlinal nose, bordered on the south by an abrupt, steep descent or fall. The top of the "water-table high" corresponds approximately with the productive area of the oil field. It is significant that in addition to the water-table terrace, there are three small artesian areas in alignment with the Salt Lake and Los Angeles City fields. In the absence of any surface topography to account for these features, the conclusion is inescapable that they are due to subsurface conditions. Well logs show that folding and faulting exist beneath the flat alluvial plain at this locality. It should be mentioned that in contouring the water table in and around the Salt Lake oil field, certain deep water wells which show abnormally high water levels should be omitted. These wells derive their water from artesian aquifers under hydrostatic head in the Pliocene strata, and their static levels represent piezometric surfaces.

Faults.—The effect of faults on the water table depends chiefly on the direction of movement of the ground water and the direction of displacement of the impervious rock floor. Where the surface has little or no topographic relief and where the fault is entirely hidden by alluvium, the water table might be forced nearer the surface on either the upthrown or the downthrown side depending on the direction of flow of the ground waters. Clark[1] describes the Niles-Irvington fault opposite the mouth of Niles Canyon, on the Niles alluvial cone in Santa Clara County, California, which has produced a conspicuous elevation of the water table on the *downthrown* side of the fault. The direction of movement of the ground water is from the downthrown side toward the upthrown side. The fault has acted as a subsurface dam, impounding the water on the downthrown side (upstream side). Had the ground water been moving in the opposite direction the water-table rise would have occurred on the upthrown side.

Another subsurface barrier which may be due to faulting is located 2 miles northeast of North Ontario, at the "Red Hills," shown in Figure 11. The Red Hills form a topographic barrier at the locality shown on the map (Fig. 9) but the sharp, steep break in the water table continues both east and west of the Red Hills, where there is no corresponding

[1] W. O. Clark, "Ground Water Resources of the Niles Cone and Adjacent Areas, California," *U. S. Geol. Survey Water-Supply Paper 345* (1915), pp. 127-68.

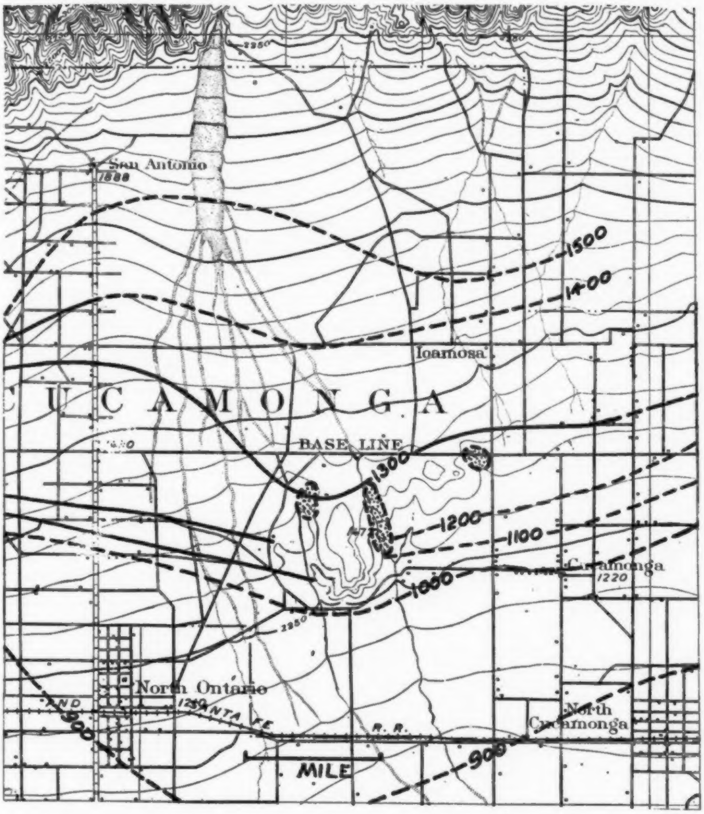

FIG. 11.—Map showing ground-water contours and artesian areas as of 1904 north of North Ontario, San Bernardino County, California. Notice steep gradient of water table along south edge of artesian areas. (After Mendenhall. Ground-water data from *U. S. Geol. Survey Water-Supply Paper 219;* contour interval, 100 feet. Topographic base: *U. S. Geol. Survey Cucamonga Quadrangle;* contour interval, 50 feet.)

continuation of the topographic barrier. Mendenhall[1] described this feature as probably due to the presence of a buried ridge of older impervious alluvium, but recent detailed investigations of the area, together

[1]W. C. Mendenhall, "Ground Waters and Irrigation Enterprises in the Foothill Belt, Southern California," *U. S. Geol. Survey Water-Supply Paper 219* (1908).

with data obtained from water-well logs, strongly suggest faulting along the line of the Red Hills "dike."

Where faults displace *artesian* aquifers the effect naturally depends on the directions of movement on the faults. The piezometric surfaces of the aquifers are affected under such conditions as well as the water table.

The only criterion known to the writer whereby it may be possible to distinguish between water-table irregularities due to faulting and those due to buried unconformities (buried ridges and eroded anticlines) is the generally observed fact that the break, or declivity, from the higher to the lower surface of the water table is steeper, more abrupt, and occupies a narrower zone on the ground-water contour map, where the irregularity is due to faulting.

No examples of water-table "highs" definitely known to be due entirely to faulting can be cited for the Los Angeles basin. Several examples are known, however, in Owens Valley and in northern California, and examples in other states have been described in U. S. Geological Survey Water-Supply Papers.

Local variations in porosity.—Water-table irregularities observed in flat areas where there is no topographic influence do not necessarily imply subsurface folding or faulting. Many such pronounced irregularities are due solely to local differences in the porosity of the water-bearing materials in the upper zone of saturation. Lenticular clay strata may cause perched water tables. Lateral differences in the nature of the material cause important differences in porosity. These conditions are the rule rather than the exception in alluvium-covered valleys and plains in a semi-arid climate, where the character of the wash from the hills is subject to rapid change. Consequently, many examples of such local water-table irregularities are to be found on ground-water contour maps of areas in southern California. Generally such local irregularities may be distinguished from those due to more important structural causes by their small areas, their very irregular shapes, and their erratic distribution.

OTHER FACTORS WHICH INFLUENCE SHAPE OF WATER TABLE

Factors other than topography, geologic structure, buried hills, and seasonal climatic changes may influence the shape of the water table and cause peculiar or puzzling "highs" and "lows." Chief among such nongeologic influences are (1) pumping of water wells and (2) irrigation of the land. Continuous pumping of wells, or intermittent pumping of a

closely spaced group of wells, tends to produce a depression in the water table, which, on a ground-water contour map, would have the appearance of a small topographic basin. Extensive irrigation of certain areas, whereby large amounts of water are added to the surface, much of which joins the underground supply, produces the opposite effect. Under such conditions small water-table "highs" or "domes" appear on the ground-water contour maps. Examples of both types of such irregularities may be seen on recently compiled ground-water contour maps of the San Joaquin Valley,[1] California.

Water-table irregularities due to pumping and irrigation may ordinarily be readily detected by checking the date and source of the water-well data and studying the locations of the wells on which the hydrographic contours are based. Such irregularities are also probably erratically distributed throughout an area with no relation to known surface structural lines.

SUMMARY AND CONCLUSIONS

The main features of the water table are controlled by the topography. The usefulness of water-table irregularities in searching for buried structure is, therefore, limited to those localities where the surface of the land is flat; consequently, where there is no topographic clue to the underlying structure. Under such conditions, some irregularities of the water table, such as anticlinal bulges or sharply defined artesian areas, may be reliable indicators of the existence and location of hidden faults or buried anticlines. In most places where the water table accurately reflects the underlying structure, the water-table bulges are primarily caused by the presence of buried hills and ridges. Therefore, the use of water-table data in the determination of hidden subsurface structure should be confined to flat areas and to localities in which the topography is known to be generally controlled by the geologic structure. A water-table "high" may very accurately locate a buried ridge or hill, but unless the buried topography is anticlinal, the water table can not be used to locate hidden folds.

The occurrence of water-table "highs" should be regarded with suspicion unless supported by other geological data such as alignment with visible structural or topographic features, parallelism with known axes of folding, or other equally significant relationships. Small, irregular, isolated, or erratically distributed water-table "highs" should be

[1]S. T. Harding, "Ground Water Resources of the Southern San Joaquin Valley," *State of California Dept. of Public Works, Divisions of Engineering and Irrigation and of Water Rights Bull. 11* (1927).

disregarded, as few reflect buried structure. Finally, the source and accuracy of the data pertaining to the water levels used in drawing the ground-water contours should be carefully investigated. Many seeming water-table irregularities shown on maps may be traced to the inclusion of elevations on piezometric surfaces with water-table elevations.

However, there are large areas in California, in the Gulf Coastal Plain, and along the Atlantic Coastal Plain, where carefully compiled ground-water data may prove helpful in geologic mapping when used under the proper limitations.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 4 (APRIL, 1932), PP. 361-371, 6 FIGS.

STRUCTURAL AND COMMERCIAL OIL AND GAS POSSIBILITIES OF CENTRAL VALLEY REGION, CALIFORNIA[1]

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ABSTRACT

Relationship of the igneous core of the Marysville Buttes to the petroliferous Cretaceous rocks is presented. Lenticular sands, buttress sands, and structural terraces, or low anticlines, around a great bow in the sediments east of Kettleman Hills, afford favorable conditions for accumulation of oil and gas. Evidence of similar general conditions north of Wheeler Ridge is presented and discussed.

In anticipation that the entire central valley region of California, including both the Sacramento and the San Joaquin basins, will be the scene of most of the future drilling activity in this state, three areas in that terrane are here presented briefly. The writer invites full discussion, which should result in increasing knowledge of the valley problems, particularly in regard to structure. In the areas herein considered, the suspected structures are largely hidden.

MARYSVILLE BUTTES

The Marysville Buttes (locally known as the Sutter Buttes) area of Sutter County is in the central Sacramento Valley. Here is a laccolith of andesite and later rhyolite intruding the sediments of the synclinal Sacramento Valley basin. The sediments which originally covered this laccolith were long ago removed by erosion. There now remains a sedimentary ring around the central igneous core, presenting an oil and gas problem that seems similar to that of the salt domes of the Gulf Coastal Plain or the volcanic plugs of Mexico. The geology of this region has been studied in detail by Howel Williams.[3]

The sediments exposed are (1) the Chico (Upper Cretaceous) series, 1,560 feet or more in thickness; (2) the Meganos (Eocene) group, embracing as a lower member the Marysville sandstones and shales, ranging

[1]Read before the Pacific Section of the Association at the Los Angeles meeting, November 5, 1931. Manuscript received, January 4, 1932.

[2]Consulting petroleum geologist, Crocker Building.

[3]"Geology of the Marysville Buttes, California," *Univ. California Dept. Geol. Sci.*, Vol 18, No. 5 (March, 1924).

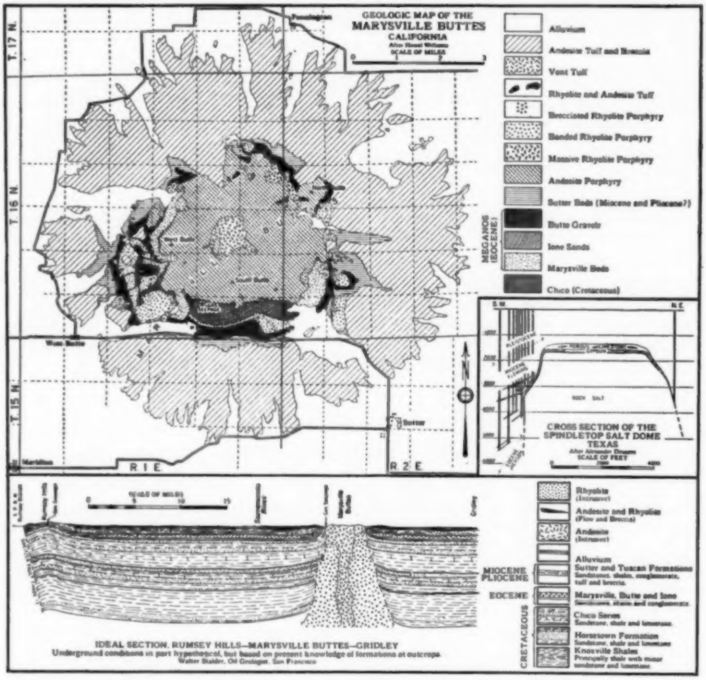

FIG. 1

from 300 to 600 feet in thickness and the Ione sandstone and Butte gravels, 100-150 feet and 1,200 feet in thickness, respectively; and (3) the Sutter sandstones, gravels, and clays, probably Miocene or Pliocene in age, 1,000 feet or more in thickness. Capping most of the Sutter beds and overlapping the older sediments in isolated masses is a cone of andesite tuff and breccia which represents the ejecta during the last period of volcanic activity, after the sediments had been removed from the crest of the mountain.

A seepage at the contact of the Chico shales with the central andesitic core on the southwest slope of South Butte, as indicated in Figure 1, stimulates an interest in the commercial possibilities of the region. It is typical of many other gas seepages in Cretaceous rocks in northern California and is accompanied by semi-fused and clinkered clay where

gas has burned in past time at the surface. According to W. L. Watts,[1] who visited this area in 1894, a well sunk to a depth of 60 feet in 1864 was still yielding through the 6-inch casing an inflammable gas which smelled of petroleum.

Although the complete section of the Cretaceous rocks of northern California is not exposed at the Marysville Buttes, observations in the more steeply tilted areas of the Coast Range mountains west of the Sacramento Valley and at other places reveal an enormous thickness of oil-yielding rocks. *Bulletin 826 of the United States Geological Survey*[2] gives a thickness of 47,000 feet for these Cretaceous beds in northern California as follows: Chico, 21,000 feet; Horsetown, 6,000 feet; and Knoxville, 20,000 feet. The oil and gas indications in these rocks are seepages of paraffine oil and gas in many localities and the odor of petroleum from the shales, particularly on hot days. At least two-thirds of these rocks are shales and limestones of oil- and gas-forming character. If the thickness of petroleum source rocks is to be regarded as the controlling factor, the amount of production to be derived from the Cretaceous rocks of northern California should greatly exceed that from the Miocene and Pliocene diatomaceous source rocks of the oil and gas fields of the southern part of the state, where a maximum thickness of 7,000 feet has been recorded.

Extending from the northern Sacramento Valley, these Cretaceous formations are found in fairly continuous outcrops well into the San Joaquin Valley, where the Moreno shales form the source rocks for some of the oil in the north end of the Coalinga oil field. The Cretaceous series is much thinner and less petroliferous in the San Joaquin Valley, however. On the east side of the Sacramento Valley the Cretaceous rocks are overlapped by later sediments and volcanic flows, but are exposed in deep canyons on the west flank of the Sierra Nevada Mountains as far north as Little Cow Creek, northeast of Redding. One mile north of Oakdale in Stanislaus County in the San Joaquin Valley, a fossil *Baculites* cored at a depth of approximately 3,000 feet indicates that this formation extends at least as far south as that on the east side of the central valley region.

At the Marysville Buttes the igneous intrusive mass of andesite and rhyolite has obviously cut through this entire thickness of petroleum-

[1] "Gas and Petroleum Yielding Formations of the Central Valley of California," *California State Min. Bur. Bull. 3* (August, 1894), p. 9.

[2] "Names and Definitions of the Geologic Units of California," compiled by M. Grace Wilmarth. *U. S. Geol. Survey Bull. 826* (1931).

bearing Cretaceous rocks; it should, therefore, afford a migrating medium for gas and oil to pass upward along the sedimentary-igneous contact and accumulate wherever suitable traps occur. Whether or not sills project into the sediments from the central mass to form one such type of trap is not known, but such traps are probably present, as are also lateral sands against the igneous core. The slightly indurated condition of the Cretaceous sediments as they abut the igneous core affords a brittle and easily fractured medium which may also be an ideal reservoir for both oil and gas.

Figure 1 illustrates the general nature of the problem. Special attention is called to the section of Spindle Top after Alexander Deussen's cross section.[1] In comparing this with the ideal section on the same plate, it will be observed that conditions along the side of the salt plug are similar to those suspected along the igneous core about the Marysville Buttes. This is revealed when the upper part of Deussen's diagram is shut from view. Attention is also called to the steeply dipping beds adjacent to the core in both areas.

The real shape underground of the inner intrusive core of the Marysville Buttes is not known and question marks are placed along this contact in Figure 1. Its true nature must be determined by the same methods used in exploring the salt domes of the Gulf Coastal Plain. Testing for oil and gas will also be a similar operation, with the advantage, however, that the knowledge gained from pioneer work in the Gulf Coastal Plain can be used to advantage in this district.

Structurally, the Marysville Buttes area is the first of its type in California to be considered as a possible gas and oil field.

KETTLEMAN FRONT AREA

As early as 1921 the appearance of petroleum globules on a water well at the west margin of the dry bed of Tulare Lake on the East Kettleman Front in Kings County led to prospecting and the Sagebrush Oil and Gas Company succeeded in drilling and controlling one good shallow gas producer, only to ruin it by excessive blowing. Subsequently many other prospect wells were drilled. Two of these penetrated the 3,000 feet or more of the Tulare (Pliocene) formation and entered the underlying Etchegoin (Pliocene) formation. Both had good oil and gas indications. The discovery of the Dudley Ridge gasser at a depth of 1,200

[1] Sidney Powers, "Occurrence of Petroleum in North America," *Amer. Inst. Min. Met. Eng. Tech. Pub.* 377 (February, 1931), p. 26, Fig. 7.

FIG. 2.—East of Kettleman Hills, strand lines of dry bed of Tulare lake form conspicuous feature. Do these lines reflect underground structure for nearly flat underlying formations? Notice their change in outline opposite outer bend of Kettleman "bow." In relation to strand lines on south margin of lake, prevailing wind is from northwest, sand storms are frequent, and dune sand is here closely associated with old shore of lake. "Bowing" of outer beds of Kettleman Hills is prominent feature.

feet in 1929 in the Tulare formation finally resulted in opening the district as a commercial gas field.

An early examination of this district revealed that the eastern margin of the Kettleman Hills changes its strike from northwest to south-southeast to form a distinct "bow" as the hills trend from their northern tip to their south dome. The strike of the beds also changes in the same manner (Figs. 2, 3, and 4). Where the beds in this bow extend to the valley they abruptly flatten. The general effect of this bowing and flattening would be to form a regional gathering ground for oil and gas which would accumulate first on any structural "high" opposite or near the crest of the bow, then to gather in quantity in any suitable trap. If

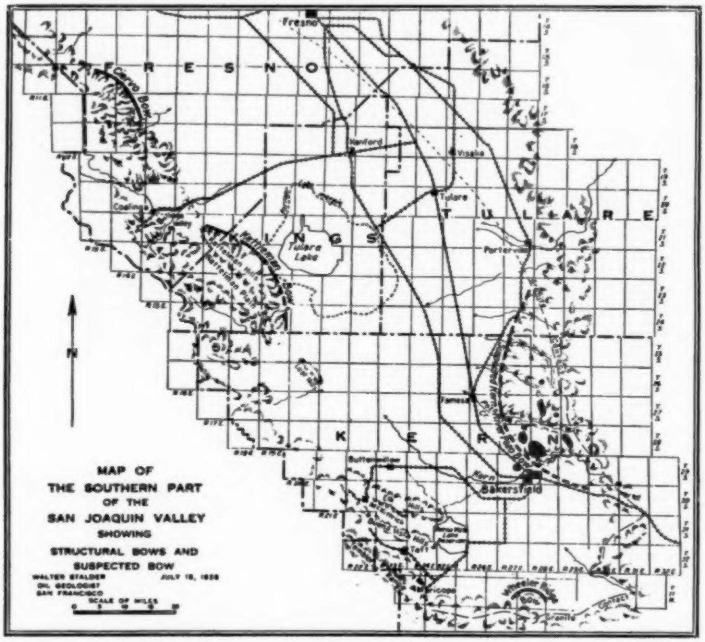

FIG. 3.—Bowing of beds in large areas is important in affording wide gathering ground and concentrating area for oil to any terrace, fault, buttress sand, dome, or other favorable structural condition included within or adjacent to bowed area. In San Joaquin Valley, Kern River-Pozo bow is believed to be important factor in productivity of Kern River, Mount Poso, North Kern River, Fruitvale, and Round Mountain fields. Other bowed areas shown on map remain to be tested adequately with properly located wells.

a trap were absent, such concentration would not occur and both the oil and gas would pass upward and escape at the outcrops of the beds.

The writer believes that a similar bow exists on the east side of the San Joaquin Valley extending from Bena Station on Walker Basin Creek through Bakersfield to Terra Bella, affording an accumulating or regional gathering ground for the Edison area, the Kern River oil field, the North Kern River field, the Fruitvale field, and the Mount Poso field. Each of these fields is an oil trap in the form of either a terrace, a fault, or a fold (Fig. 3).

Suitable traps possibly existing on the East Kettleman Front are terraces, buttress and truncated sands[1] due to the unconformable relation of the Tulare and Etchegoin formations, lenticular sands, or a low fold parallel with the strike of the beds adjoining and beyond the east margin of the Kettleman Hills (Fig. 4). Faulting, also, may be a factor in such concentration, but in the vicinity of the old bed of Tulare Lake such faulting is difficult to establish. An endeavor to duplicate in paper models the crustal movements around the Kettleman Front resulted in a somewhat triangular structure, partly a parallel fold, somewhat like a terrace and seemingly with a dome-like structural "high" opposite the outer bend of the bow (Fig. 4).

Pertinent facts and ideas in connection with this area are as follows.

1. The fresh- and brackish-water deposits composing the Tulare formation are richly organic. The lake bed at the time of this deposition must have teemed with life, as evidenced by the myriads of diatoms, ostracods, mollusks, and plentiful fish remains there present. For this reason the gas and the oil found in the Tulare formation are considered as indigenous.

2. Wells drilled to date have not determined the true outline of the underlying structure.

3. Abrupt differences in the nature of beds from well to well prove lenticularity.

4. Productive wells so far have been found only within a reasonable distance from the bending bow.

5. The shale outcrops of the underlying Etchegoin formation below the Mya-Natica horizon on the east flank of the Kettleman Hills contain diatoms. They are, therefore, a probable source of the oil encountered in deep wells on the flat. As off-shore deposits, these Etche-

[1] E. R. Atwill, "Truncation of Maricopa Sandstone Members, Maricopa Flat, Kern County, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 6 (June, 1931), pp. 687-96.

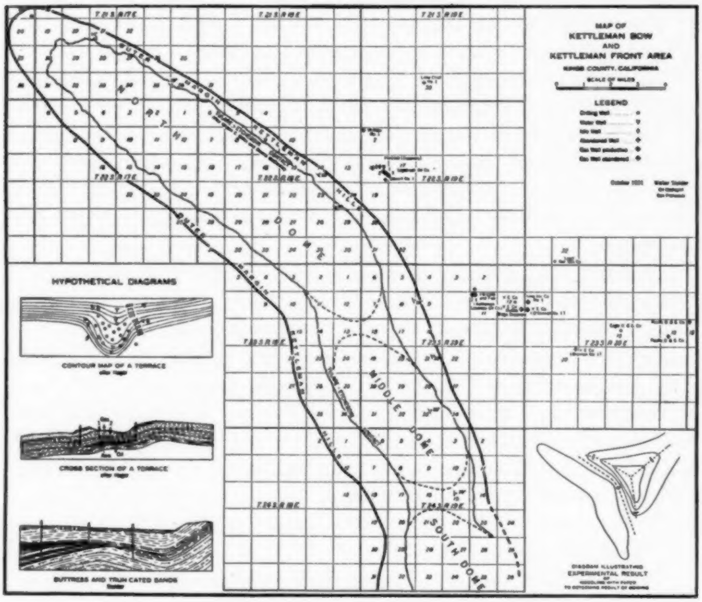

Fig. 4

goin shales may be much thicker and more diatomaceous than at their outcrops. In this connection attention is drawn to the fact that the brown Temblor shales underlying the Kettleman Hills are represented by sands at their outcrops northwest of Coalinga.

6. The gas and oil of the East Kettleman Front have no connection with the oil and gas of the Kettleman Hills field.

7. The diatomaceous nature of the shales of the Etchegoin formation as aforementioned suggests that oil and gas found elsewhere in these beds on the margin of the San Joaquin Valley may have originated in the Etchegoin formation itself, rather than in the underlying Maricopa shales, to which most of the oil of the West Side fields has been previously attributed.

WHEELER RIDGE FRONT

Around the north flank of Wheeler Ridge, Kern County, beds of the Tulare (Pliocene) formation are distinctly bowed as they turn to form the north part of the Wheeler Ridge dome. This is illustrated in

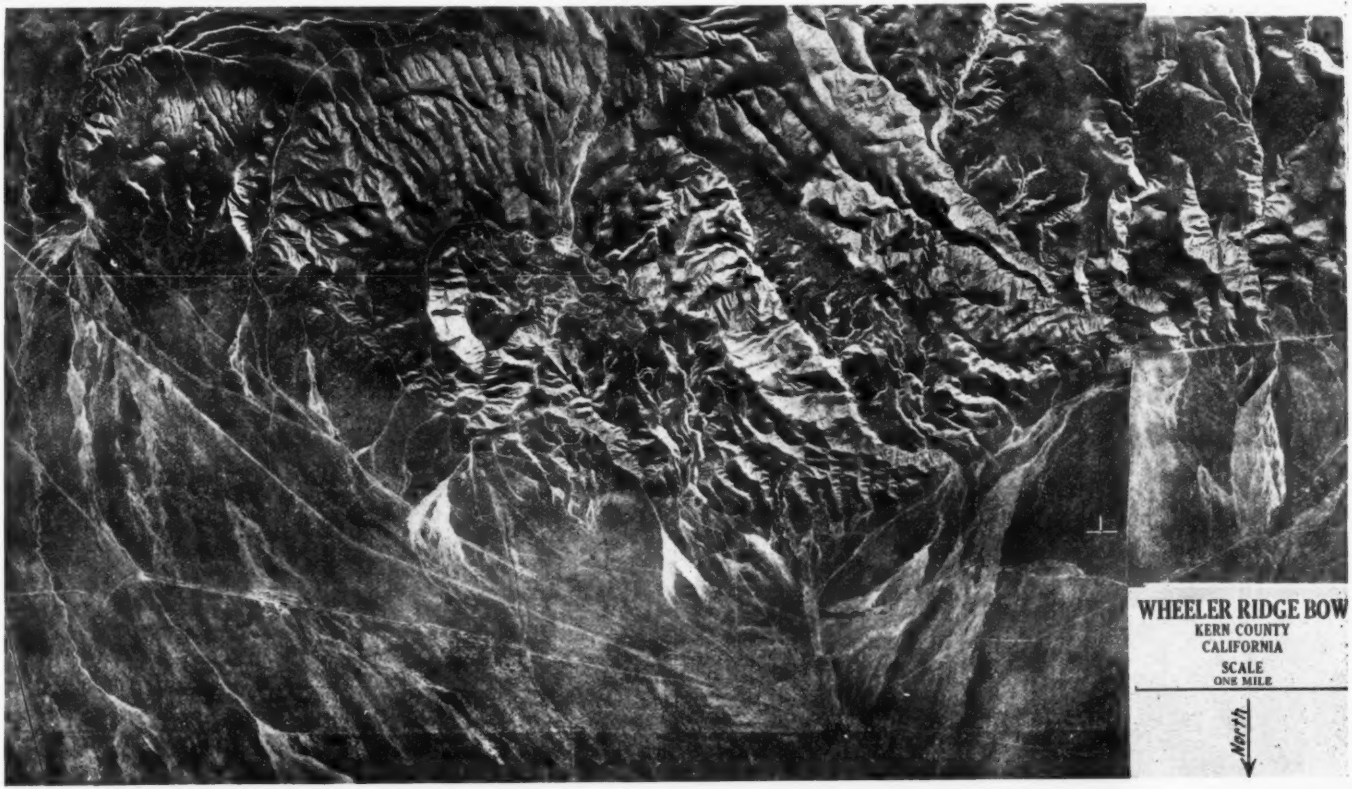

FIG. 5.—Flat immediately north of eminence of Wheeler Ridge is distinctly bowed at junction with hills. By studying topography in hills and projecting outcrops into flat, it will be observed that stream courses approximately mark bowing of beds beneath flat as they change their strike around north flank of dome. Stream deposits at mouths of canyons may affect this condition slightly, but broad effect is not altered. Bow on north flank of structure beneath flat is alluring because of prolific producers obtained by careful drilling of somewhat similar north flank of Thirty-Five anticline 18 miles north-northwest of Wheeler Ridge.

the accompanying mosaic (Fig. 5). In addition to the bowing, these beds flatten within a short distance toward the valley, giving the general effect of a broad northward-plunging and flattening nose.

Oil-stained sands in the Etchegoin (Pliocene) formation are found in several well marked exposures in Coal Oil Canyon, which crosses the Wheeler Ridge structure. Wells drilled at the axis of the fold have disclosed that these are tar sands. Oil is produced here from the underlying Brown (Maricopa) shales.

The relation of the Etchegoin formation to that of the Maricopa shales throughout the southern San Joaquin Valley is one of marked unconformity. On the Thirty-Five anticline of the Maricopa Flat in southwestern Kern County this condition has caused several buttress or lateral sands which have afforded a most remarkable oil production. This condition has also caused truncated sands in the Maricopa shale, as described by E. R. Atwill. A similar condition is also most logical to expect beneath the flat north of Wheeler Ridge. The bowing and flattening will tend to concentrate migrating oil and gas from the valley toward the center of the bow, or nose, to be trapped in any buttress or truncated sands or possibly against any other favorable barrier on the bow such as a fault or a terrace. Figure 6 illustrates this suspected buttress and truncated sand

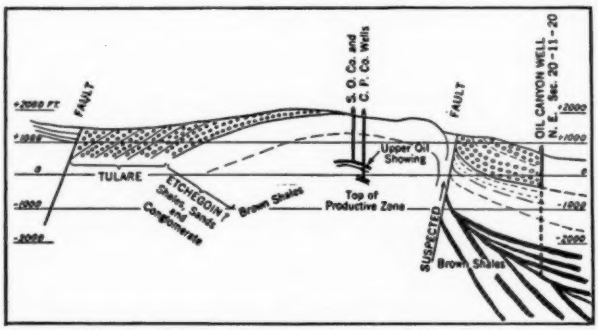

FIG. 6.—North flank, Wheeler Ridge. Suspected faulting, buttress and truncated sands. Section at left of suspected fault adapted after George M. Cunningham, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 5 (May, 1926), p. 500, Fig. 2.

effect. Developments on the Thirty-Five anticline most certainly support the idea of such buttress sands for the Etchegoin and Maricopa shale formations of Wheeler Ridge.

Overturning and faulting are also in evidence on the north flank of Wheeler Ridge. At and near the contact of the Etchegoin and Tulare formations in Coal Oil Canyon, dips ranging from 67° to 80° toward the south have been measured in the Etchegoin shales. If the fold were here asymmetric, as stated by previous writers, these dips should be toward the north. Evidence of this overturning occurs in gulches at intervals for almost a mile east of Coal Oil Canyon, beyond which it is obscured by a landslide and cross fault, whereas west of Coal Oil Canyon on the same general line, landsliding, buckling, and perpendicular and overturned beds suggest that these irregularities are also accompanied by faulting. On the eastern end of the structure, buckling and perpendicular beds abruptly occurring in more gently dipping strata indicate a disturbance other than gentle folding to form a simple asymmetric fold.

As the Pleito fault immediately south of Wheeler Ridge is a large overthrust from the south, secondary faulting can be most logically expected to accompany the overturning and the other irregularities observed in Wheeler Ridge and it is the most reasonable cause of the two well marked landslides on the north flank of the ridge.

Though such faulting will not adversely affect, but will probably favor, concentration of oil in buttress or truncated sands around the bow, it affords an excellent explanation for the failure of wells in the Etchegoin formation near the axis of the structure as well as the comparatively small production from the Brown (Maricopa) shales in the same area, for such faulting has undoubtedly arrested migration from the large gathering ground of the San Joaquin Valley to the crest of this structure.

If comparisons are to be made, it may be noted that "gusher" production from the now fairly well tested Thirty-Five anticline was first obtained from buttress sands on its north flank and down its eastward-plunging axis, whereas wells in the truncated sands in the underlying Maricopa shales are of late development and are not as productive as those in the buttress sands, though they would be considered as remarkable producers if compared with present producers at Wheeler Ridge. At Wheeler Ridge, Maricopa Brown shale production has been the earliest and only development and the bowing north flank and eastward-plunging end have not been adequately tested for the type of larger production from buttress or truncated sands. Structural conditions north and on the east end of Wheeler Ridge, have, therefore, a seemingly much greater importance than the crest of the fold near the top of the ridge.

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PERMEABILITY, ITS MEASUREMENT AND VALUE[1]

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ABSTRACT

The distinction between permeability and porosity is drawn, and the need for this is emphasized. The importance to the oil industry of securing reliable permeability data is demonstrated. Testing of permeability is discussed and a standard method is suggested.

During the past few years a concerted effort has been made by petroleum engineers to learn more about the many factors which influence the production of oil and gas in proved fields. The general laws that govern the movement of oil and gas from a sand to the top of a well have been established, but the variables which determine the practical application of these laws are, by many investigators, either overlooked or misinterpreted. Indeed, under some conditions, methods for measuring these variables have not been developed to the point where the data obtained are reliable. It is the purpose of the writer to discuss briefly, in a non-technical manner, the important variable *permeability*, and to emphasize the need of standardizing a method for measuring it.

PERMEABILITY VERSUS POROSITY

To the average operator the terms permeability and porosity are synonymous, and even in the technical literature this confusion of unlike properties appears. A few sentences from various sources may be quoted to illustrate. "The fact that water moves so easily through a part of the sand that contains no oil, even if it is of relatively lower porosity, indicates the oil itself resists displacement by water." "The greatest rate of production will be found in areas of largest average pore space, regardless of relation to structure, and the largest output per day will also be found to depend on the average percentage of pore space." "The Bradford sand has lent itself to flooding successfully because it is comparatively regular in thickness and its porosity varies but slightly." In

[1]Manuscript received, January 11, 1932. This study has been made possible through a grant from the Hecksher Research Fund at Cornell; a grant from the Research Committee of The American Association of Petroleum Geologists; and with the use of many core samples generously contributed by members of the Association

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each of these quotations, permeability and not porosity is the controlling factor.

The distinction between porosity and permeability is not merely one of academic definition or usage. The two properties are different and the tests which determine them are dissimilar. Aside from the fact that a substance must be porous in order to be permeable, porosity and permeability have no relation. A sand with low porosity may have relatively high permeability, and the high porosity of many shales is coupled with a very low permeability.

The porosity of an oil sand is the ratio of the pore space or voids to the volume of the sand. If all of these interconnect, the entire pore space forms an effective reservoir (known as effective pore space), thus representing the capacity of the sand for storing oil and gas.

Permeability may be defined as that property which permits liquids and gases to pass through a porous substance. As used here, it is distinct from the penetration of liquids by adsorption. Until a liquid has penetrated through an oil sand, the rate of flow is caused by a combined pressure and capillary action; but after penetration is complete, the rate of flow is governed by differential pressure. This rate of flow is a measure of the permeability of the material.

Fettke[1] and Barb,[2] during their detailed studies of many cores from the Bradford sand of northwestern Pennsylvania, have found a seeming relation between porosity and permeability, a high porosity denoting a relatively high permeability. Porosity determinations are easily made and the suggestion has been advanced that porosity tests could be used as a measure of permeability.

No doubt, this suggested relation of permeability to porosity is supposed to apply only within the limits of one field, and particularly where the sand conditions are fairly uniform. The pebbly phases of the Bayard sand of Pennsylvania, for example, would be too dissimilar from a fine-grained, tight sand to admit of permeability comparisons, though their porosities were the same.

The writer's experiments with the Bradford sand of Pennsylvania, the very formation which was used to substantiate this supposed relation of permeability to porosity, have shown the fallacy of using porosity as an indication of permeability, even as a short cut. Additional evidence

[1]C. R. Fettke and W. A. Copeland, "Permeability Studies of Pennsylvania Oil Sands," *Amer. Inst. Min. Met. Eng. Petrol. Dev. and Tech.* (1931), pp. 329-39.

[2]C. F. Barb, "Porosity-Permeability Relations in Appalachian Oil Sands," *Pennsylvania State Coll. Min. Indus. Bull. 9* (1930), pp. 47-59.

is given by Nutting,[1] the following data being taken from his tests on the Bradford sand.

Permeability	*Porosity*
7.9	15.3
1.1	15.9
1.2	19.4

When the pore spaces in sands are studied under a microscope, preferably binocular, the reason is easily seen for two sands with nearly the same porosity having very different permeabilities. If the sand has been settled in water and jarred to maximum density, the diameter of the average pore opening is approximately one-fifth of the diameters of the most plentiful sand grains. Cemented sands and sandstones may show a much greater diversity in the size of the pore spaces, many of their voids being several times the size of the average sand grain; and these areas of relatively large pore spaces are interspersed with patches that are tightly cemented. Thus, two sands with the same porosity or capacity to hold liquids and gases may be entirely unlike in their ability to allow liquids and gases to flow through, because of the existence in one of them of a series of relatively large, open voids. Moreover, if a sand is screened so as to get samples comprising grains that are just caught on the 20-mesh sieve and grains that are 100-mesh in size, the porosities of these two screenings will be approximately the same if the sands are deposited so as to give maximum density; but the permeability of the sample caught on the 20-mesh screen will be far greater than of that caught on the 100-mesh screen.

Therefore, it will do no harm to repeat that, aside from the requirement that a permeable substance must be porous, permeability and prosity are unrelated. The use of porosity data as a basis for estimating the flow of liquids and gases through oil sands is certain to result in misleading conclusions.

PRACTICAL VALUE OF PERMEABILITY DATA

The question naturally arises, what value, if any, will permeability measurements have? To the technician the answer is obvious, but to the practical operator the permeabilities of a series of wafers cut from oil sands are of little interest at present. It seems worth while, therefore, to indicate a few conditions under which the knowledge of permeability is essential.

[1] P. G. Nutting, "Some Physical Problems in Oil Recovery," *Oil and Gas Jour.* (November 21, 1929), p. 44.

Correct spacing of oil and gas wells, so as to give the most economical recovery, is a difficult problem. Of course, in many places, the offset requirements, the shape of the property, or the need for large production early in the life of a field, have caused overdrilling. Although a field may have been developed under normal conditions, spacing of wells may be an uncertain proposition based on experience in some other supposedly similar field. The location of gas wells 1,250 feet apart or the drilling of one oil well to each 2 acres is correct only if sufficient data of a favorable nature have been gathered.

Leases that were thought to have been completely drilled have been abandoned before it was discovered that additional new wells spaced between the old wells would give a profitable return. Tight sands (incidentally, "tight" is the common term for low permeability) certainly require a closer well-spacing than an open, permeable sand. However, overdrilling is of ordinary occurrence. It has been stated that the great Humble oil field, in which has been produced more oil than in any other field in the Gulf Coast region, has failed to yield enough oil to repay the drilling and pumping costs. Obviously, the wells must have been incorrectly spaced.

Aside from economic considerations such as the price of oil and the cost of drilling, among the most important factors which determine the proper spacing of wells are: the rock pressure; the type of control under which the field is producing, whether hydraulic, volumetric, or capillary; the viscosity of the oil; saturation of the sand; the thickness of the producing horizon; and the average permeability of the sand.

Each of these factors, with the exception of permeability, may be closely approximated without much trouble. In other words, if the permeability of the sand is known, the proper spacing of wells may be determined with a fair degree of certainty.

Aside from the necessity of having present a large amount of unreclaimed oil, the value of repressuring with either air or gas and the value of water flooding are almost directly governed by permeability conditions in the productive horizon. Open, permeable streaks allow bypassing of the air, gas, or water, and the oil is trapped in the tighter, less permeable zones. To direct flooding and repressuring programs intelligently, the petroleum engineer should have complete data on the permeabilities of the sand.

Let us see what help may be given by the permeabilities of a series of cores obtained from a sand which is to be flooded. If the upper part of this sand shows a gas zone, containing little if any oil, this must be

sealed. Any pressure drive, whether it be gas, air, or water, will short-circuit through a sand zone that is not fairly well saturated with oil because it is easier to displace air than a liquid. This greater permeability of an oil-free zone is easily demonstrated in the laboratory, if the time it takes a water front to pass through a long column of sand whose voids are filled with air is contrasted with the time it takes a water front to pass through the same sand after it has been saturated with oil, the pressure on the drive remaining unchanged. Failures of many flooding and repressuring programs may be attributed to the neglect of this obvious factor.

With permeability data from the cores of the saturated part of the sand, the engineer is in a position to determine approximately the pressure to use on the drive in order to get the best results. This is especially true if permeability data on other sands which have been successfully flooded, are available. And most important of all, if the data indicate very marked differences in permeabilities of the sand, both horizontally and vertically, the engineer knows that a large amount of by-passing and trapped oil will result unless special precautions are taken.

Great variation in permeability (a condition more common than is recognized) may be overcome to some degree by careful back-pressuring at producing wells, thus reducing by-passing to a minimum. Or if a water drive is being carried on, the delayed drilling of the central well in a "five spot," as advocated by Torrey,[1] will overcome much of the trouble arising from extreme variations in permeability. Under a relatively low pressure, the water will drive the oil from the most permeable sand streaks and concentrate it toward the center of the five-spot squares. An increased pressure will then cause water to displace oil from the less permeable streaks because the capacity of the high permeability zones to hold a fluid has already been reached. If this high pressure had been applied earlier, or if drilling of the central well had not been postponed, the water flood would have held to the streaks of greatest permeability and a large percentage of oil would have been trapped in the less permeable lenses.

MEASUREMENT OF PERMEABILITY

It might seem that the rate of flow of water through a sand sample should continue unchanged with the passing of time, provided the pressure and viscosity remain constant. Unfortunately, this surmise is not

[1] P. D. Torrey, "Modern Practice in Water Flooding of Oil Sands in the Bradford and Allegheny Fields," *Amer. Inst. Min. Met. Eng. Petrol. Dev. and Tech.* (1930), p. 272.

true. Nearly fifty years ago, F. H. Newell,[1] in a "Thesis on the Geology of the Bradford Oil Rocks; Some Experiments Pertaining to their Structure and Capacity to Furnish Petroleum," pointed out that the rate of flow of distilled water, crude oil, and kerosene through sandstones diminished with time. Subsequently, many investigators have noted this falling off of permeability with time. The writer has frequently found a reduction of more than 50 per cent in permeability during one hour.

Among the various suggestions that have been advanced to explain this are: adsorbed air that is trapped in the sample producing a Jamin effect; a clogging action caused by the filtering of particles from the oil or water; loose débris from the face of the sample carried into the pore spaces; hydration and swelling of the bonding material; rearrangement of the sand grains during the test; unstable oil films on the sand grains; and gummy deposits from the crude oil. It is admitted that any of these factors will decrease permeability, but strangely enough, even after precautions have been taken to remove these causes, the decrease continues. It is, of course, necessary to remove the cause of this decrease in permeability because, unless the rate of flow is kept constant with time, permeability data by different investigators are not comparable. In fact, the true permeabilities of the samples are not otherwise determined.

It has remained for Botset[2] to discover additional factors which produce the decreased permeability previously noted. His studies indicate that slowing of the flow of water is the result of hydrolysis of silica by water in which silicic acid is produced. Probably colloidal silica is also formed and this would clog the pores of the sand. If permeability is determined with crude oil and kerosene, clogging is caused by unsaturated hydrocarbons which tend to oxidize and form more or less gummy substances. Botset's conclusions are:

> Permeability measurements with water are open to doubt unless extreme precautions are observed to prevent hydrolysis. Experiments on the flow of oils through porous media become open to question, especially if applied to field conditions, unless made in the absence of air or unless the oils used contain no unsaturated hydrocarbons.

With these conclusions the writer is in hearty agreement. Some degree of gumming of the sands when an air drive is used, and a clogging of the pores because of hydrolysis when a water drive is used, seem to be expectable.

[1]Quoted by F. H. King, *U. S. Geol. Survey 19th Ann. Rept.* (1897), Pt. 2, pp. 124-35.

[2]H. G. Botset, "The Measurement of Permeabilities of Porous Alundum Discs for Water and Oils," *Review of Scientific Instruments*, Vol. 2, No. 2 (February, 1931), pp. 84-95.

Early in the course of the writer's investigation it was found that neither oil nor water was a satisfactory fluid with which to measure the permeabilities of a series of oil sands. Therefore, during the last three years all permeabilities have been determined with air. This has proved to be very satisfactory, because the rate of flow remains constant with the passing of time, if the air is dry so that no moisture condenses and clogs the pores of the sample. Duplicate checks are easily obtained. Also, by using the permeability to air, the rate of flow of water, oil, and other liquids whose viscosity is known, may be calculated. It is suggested that air should be used as a standard with which to measure the permeability of oil sands.

APPARATUS AND TECHNIQUE

An ordinary 2-stage air-compression pump, such as is found in many garages, was used to compress the air into a large supply reservoir. This tank is 5 feet in length and 2 feet in diameter, and it is essential that the tank be large because, if its volume is small, the pressure drops rapidly as air is withdrawn with the result that it is difficult to pass air through the sample under a constant pressure.

A most important piece of apparatus is the reducing valve, which is connected between the reservoir and a gauge that measures the pressure of the air as it passes through the sample. The reducing valve is furnished with two interchangeable springs, for high and low pressures. The setting of this valve to maintain a specified pressure on the sample is most easily done when the pressures on the opposite sides of the reducing valve are not too far apart. That is, if air is to be passed through a sample at a pressure of 40 pounds, the air in the reservoir should be at a pressure of approximately 200 pounds; air flowing through the sample under a 2-pound pressure should be fed from the reservoir to the reducing valve at a pressure of approximately 20 pounds. With this arrangement it is possible to keep air flowing through the sand sample at a constant pressure, with little or no adjustment being required during a determination.

The rate of flow was usually measured by reading, on a split-second stop-watch, the time required for 10,000 cubic centimeters of air to pass through the sample. This air was measured by displacing 10,000 cubic centimeters of water in a large bell jar, care being taken to see that the 10,000-cubic centimeter water level in the jar was even with the water level outside the jar, so that the volume of the air within the jar was under atmospheric pressure. In some determinations the quantity of air was measured with a gas meter.

The sample to be tested was first blocked out roughly with a hacksaw and reduced to the desired shape on a high-speed, coarse emery wheel. The height of the sample was ordinarily ½ inch and the sample was ground so that it was circular in cross section, the diameter ranging between ½ inch and 2 inches.

Brass mountings, somewhat similar to the type described by Melcher,[1] were used to hold the specimens. Different cements were tried and it was found that sealing wax was best for high pressures, and that ordinary modeling clay worked very well with low pressures. When sealing wax was used, it was flowed in around the sample with a fine-pointed electric soldering iron. If a very friable sand is to be tested, it should be supported on a wire screen to keep the sample from breaking down when pressure is applied.

Practically all samples must be treated to remove the oil, before testing them for permeability. Carbon tetrachloride is certainly the safest solvent and it was found to be very satisfactory, provided some type of a reflux condenser was used so that the sample was always receiving pure liquid. As carbon tetrachloride boils at 76° C., it was not necessary to heat the sample above 110° C., even when drying it out. At temperatures above this, the bonding material may dehydrate and fictitious permeability values will be obtained. If the sand sample has been exposed to the atmosphere for some time, the oil becomes inspissated and tarry products are formed which are not completely removed by ordinary solvents; thus the true permeability of the sand is not determined. It was found that removal of the oil was speeded if the samples were soaked in carbon tetrachloride under a partial vacuum, at the beginning of, and several times during, their treatment in the reflux condensers.

If the sand is poorly consolidated, like many of the California oil sands, removal of the oil may give a mass of sand grains that are not sufficiently cemented to be tested in the usual way. In fact, the best procedure is to pass the oil-free sample through a nest of sieves, so as to destroy all compound grains, and test the loose sand after thoroughly mixing it. To get reliable results, a sample large enough to give a cross section ranging from 1 inch to 2 inches and a height of 2 inches, is necessary. Of course, the permeability of the sand as it actually occurred in the ground is not obtained in this way, but one does get a permeability

[1]A. F. Melcher, "Apparatus for Determining the Absorption and the Permeability of Oil and Gas Sands for Certain Liquids and Gases Under Pressure," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 3 (May-June, 1925), pp. 442-50.

figure from which useful comparisons may be made with other unconsolidated oil sands.

EXPRESSION OF PERMEABILITY

There are, in general, two types of flow when liquids and gases pass through an oil sand; namely, turbulent and viscous. During the early life of a well having large production, the laws of turbulent flow no doubt control; later, when the flow is much smaller, it is of the viscous type. Throughout the life of the field, viscous flow best describes the movement of oil, gas, and water through the sand some distance from producing wells. It seems, therefore, that the permeabilities of oil sands should be tested under conditions which give relatively small flows, conditions which approximate the viscous rather than the turbulent type.

It was found that a flow of 10,000 cubic centimeters of air could be measured accurately between the time limits of 10 seconds for a high rate and 30 minutes for a low rate of flow. As the air pressure could be varied through a range from a few ounces to 250 pounds, a pressure was usually chosen such that 10,000 cubic centimeters of air passed through the sample in a period ranging from 30 seconds to 3 minutes, which, it is thought, gives a condition analogous to viscous flow. By keeping the rate of flow of air within these limits, the following relations were found to hold.

1. The rate of flow varies directly as the cross-section area of the sample. If other factors remain unchanged, a sand with a cross section of 2 square inches gives one-half the flow that the same sand gives with a cross section of 4 square inches. Or, if the rate of flow through the sample of 4 square inches is divided by two, the permeabilities of the two samples are equal, as they should be. This relation of the rate of flow to the cross-section area was studied between the limits of samples with a diameter of ½ inch and those having a diameter of 4 inches.

2. The rate of flow varies inversely as the height of the specimen. A sample 10 inches high would give one-fifth less flow if it were only 2 inches high. The effect of the thickness or height of the sample was studied between the limits of 1 inch and 23 inches.

3. The rate of flow varies directly as the pressure. With a 10-pound pressure, a sample transmits five times as much air as it does with a 2-pound pressure. Or, stated in another way, with a 40-pound pressure, air flows through a sand twice as rapidly as it does when under a 20-pound pressure.

This law, which has been termed either Darcy's law or Poiseuille-Meyer's law, is thought by King[1] not to apply to the movement of liquids or gases through sand. In the writer's investigation it was found to hold exactly if the flow did not become turbulent.

4. The rate of flow varies inversely as the viscosity of the liquid or gas passing through the sand. A high viscosity is coupled with a relatively small flow.

If these statements are accepted, we may set up the following general formula as an expression of permeability.

$$\text{Permeability} = \frac{\text{quantity of liquid or gas} \times \text{height of specimen} \times \text{viscosity factor}}{\text{time} \times \text{cross-section area} \times \text{differential pressure}}$$

With such a formula, data secured by different investigators, using a variety of sizes of samples and magnitudes of pressure, may be recalculated to a comparable basis. It is suggested that the viscosity of water at 20° C. (68° F.), which is 0.01006, be considered unity. The viscosity of air at this temperature is 0.00018, which is approximately 60 times less than that of water. As variations in the viscosity of air with temperature changes are very small, this viscosity factor of 60 may be used in all ordinary measurements of permeability with air.

As an example of the usefulness of this permeability formula, let us take two determinations expressed in different units and show how they may be compared.

Example 1.—Given a sample ½ inch high and 2 inches in diameter that transmits 610 cubic inches of air in 1 minute and 30 seconds, with a pressure of 40 pounds:

$$\text{Permeability} = \frac{610 \times 2 \times 60}{1.5 \times 3.14 \times 40} = 388$$

Specifically, the flow is 388 cubic inches of air, per minute, per pound pressure, per inch height of specimen, per square inch of cross-section area.

[1]F. H. King, "Principles and Conditions of the Movement of Ground Water," *U. S. Geol. Survey 19th Ann. Rept.*, Pt. 2 (1899), pp. 107-206.

Example 2.—Given a sample 1 centimeter high and 5 centimeters in diameter that transmits 10,000 cubic centimeters of air in 30 seconds, with a pressure of 80 pounds:

$$\text{Permeability} = \frac{10{,}000 \times 1 \times 60}{0.5 \times 19.64 \times 80} = 764$$

Specifically, the flow is 764 cubic centimeters of air, per minute, per pound pressure, per centimeter height of specimen, per square centimeter of cross-section area.

Example 3.—If the permeability of Example 2 is expressed in terms of Example 1 the result is:

$$\text{Permeability} = \frac{610 \text{ cu. in.} \times 0.394 \text{ in.} \times 60}{0.5 \text{ min.} \times 3.04 \text{ sq. in.} \times 80} = 119$$

Or, the sand represented by sample 2 has less than one-third the permeability of sample 1, the proportion being as 119 to 388.

POSSIBILITY OF CALCULATING FLOW OF LIQUIDS FROM PERMEABILITY TO AIR

Thin films of liquids and gases are adsorbed on the surfaces of sand grains, the thickness of the films ranging from 50 to 100 molecules, far too small to be measured with the highest-powered microscope. These adsorbed films are held tightly, the pull of silica on water being, according to Nutting,[1] approximately 17,000 atmospheres, which is of the same order of magnitude as the tensile strength of quartz. During a permeability experiment, the liquid or gas that flows through the sand can not use the entire openings between sand grains because these pores have been slightly reduced by the thicknesses of the adsorbed films already mentioned.

Although this property of adsorption is specific, for any temperature and pressure, as the amount of adsorption varies with the liquid or gas and with the nature of the solid, it is suggested that the thickness of an adsorbed film of air on sand grains is comparable with that of an adsorbed film of water. If this is true, the difference between the rate of flow of air and water through an oil sand depends principally on their difference in viscosity, especially if turbulent conditions of flow are not approached.

The following data from the permeability tests of five different sands substantiate this assumption. As no special effort was made to prevent

[1]P. G. Nutting, "The Adsorptive Force of Silica for Water," *Jour. Phys. Chem.*, Vol. 31 (1927), pp. 531-34.

hydrolysis, clogging with trapped air, et cetera, the maximum flow of water occurred during the first minute of elapsed time; hence this quantity has been used to represent the permeability to water.

C. C. Air Per Minute	*C. C. Water per Minute*	*Temperature Water °C.*	*Ratio Air: Water*	*Viscosity Ratio*
5,200	80	25	65	50
11,000	165	22	67	53
28,600	525	21	54	53
33,333	566	18	59	59
6,250	108	20	58	56

On the assumption that the difference between the rate of flow of air and water through a sand is largely determined by relative viscosities, in Example 1 a flow of 388 cubic inches of air corresponds with 6.4 cubic inches of water per minute; and in Example 2 a flow of 764 cubic centimeters of air represents 12.7 cubic centimeters of water per minute, at a temperature of 20° C. If this assumption is established, there is little need to try to measure the permeabilities of oil sands with water or oil; thus we can avoid the attendant uncertainties caused by a decrease of permeability with the passing of time when these liquids are used.

In conclusion, there seems to be no question of the immense value of permeability data to the oil industry. The need for expressing this information in such a way that it is comparable under a variety of conditions is evident.

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DISSEMINATED OIL IN PLEISTOCENE WATER SANDS OF CORPUS CHRISTI AREA, TEXAS[1]

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ABSTRACT

Minute globules of oil occur in water pumped from Lissie and Beaumont sands of the later Cenozoic of the Texas Gulf Coast. Such oil was observed in 27 per cent of the wells completed in these formations which were visited in San Patricio and Nueces counties.

The conclusion is reached that the oil is probably indigenous to the water sands and disseminated in them in minute quantities.

The oil seems to be petroleum. Its films resemble those of Gulf Coast terpene. In a part of the area it is associated with free sulphur in as many as 45 per cent of the wells containing oil.

It is not known whether oil in such slight concentration occurs in sediments at the time of their deposition. This oil in very late Cenozoic beds may represent the type of the most recent formation of petroleum in Texas. The evidence presented is believed to admit such a conclusion to serious consideration. It is recognized that such an assumption rests on a series of postulates not fully proved to be true, but it indicates an approach to an important phase of the problem of the origin of petroleum. If, however, vertical migration of gas into these beds has occurred, the oil (terpene?) may have come up vaporized with the gas. Terpene vapor is commonly associated with the natural gas of the area.

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INTRODUCTION

The writer has observed in water from shallow water sands of the Corpus Christi area minute quantities of oil, visible as tiny globules rising slowly to the surface and forming iridescent films which at some

[1]Read before the Association at the San Antonio meeting, March 19, 1931. Manuscript received, February 1, 1932.

[2]Consulting geologist, Box 112.

wells disappear quickly but at others remain on the surface, appearing to be brittle and waxy. The area in which the oil occurrences were studied is shown in Figure 1, and is confined to San Patricio and Nueces counties.

The oil seems to be petroleum and to be widespread in the water sands of the Beaumont and Lissie formations of the area, where these have not been invaded by surface water from overlying dune sand.

In order to discuss the significance of this oil, it is necessary to outline what is known of the geology of the area.

SURFACE GEOLOGY

In the coastal lagoon and east of it at the gulf shore are sand islands, with sand dunes along the shores of the offshore bar of Padre and Mustang islands. A zone 3 or 4 miles wide at the western shore of the coastal lagoon has a veneer of wind-blown sand, which represents a former offshore bar now driven in upon the land by the wind. This wind-blown sand rests on the Beaumont, a late Pleistocene formation of clay and sand.

The Lissie sands underlie the Beaumont. This formation consists of lenticular sands in clay. The very generalized Beaumont-Lissie contact as mapped by Deussen (**2**, 1924)[1] is shown in Figure 1. Lobes of sand of Lissie type, largely of fluvial origin, which extend eastward from this contact line, are not shown. The wells west of this line, indicated in the figure, are thought to be completed in sands of the Lagarto formation, which lies below the Lissie.

The soil map of the area (**4**, Mangum, 1911) shows irregular patches of sand and sandy loam on the surface of the Beaumont clay. These seem to be natural levees and delta distributary ridges of Nueces River formed before its entrenchment; also, probably some dunes of drifted sand, as well as outcrops of sandy lenses.

The land is a smooth plain sloping approximately 2½ feet per mile toward the coast. Nueces River has an entrenched valley 4 miles wide with walls ranging from 25 to 85 feet in height in this area. A very few creeks with narrow, shallow courses occur.

The topography is well shown on six sheets,[2] Aransas Pass, Corpus Christi, Crane Island, Oso Creek, Petronilla, and Robstown; and the general geology has been described by Deussen (**2**, 1924).

[1]Numbers in bold face type refer to appended bibliography.

[2]U. S. Geological Survey topographic quadrangles (15 minutes), except Crane Island, a U. S. Engineer map (C. of E.). Scale: 1 to 62,500. Contour interval, 5 feet.

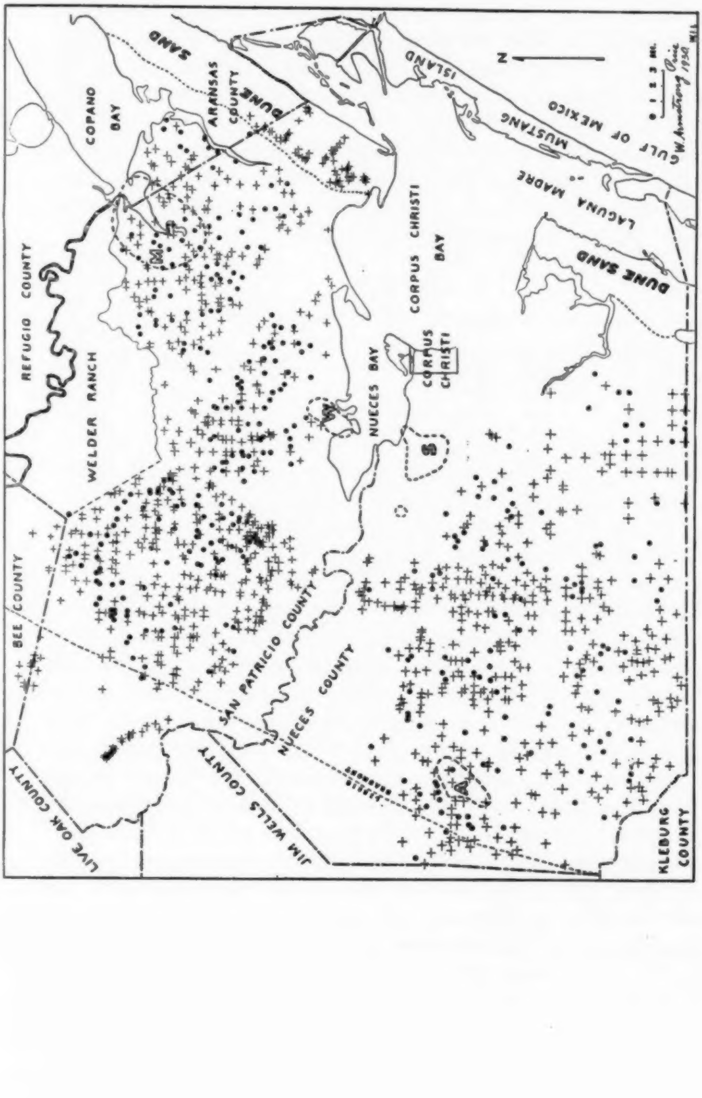

FIG. 1.—Occurrence of oil shown by dots. Absence of oil in wells when visited shown by crosses. Structures outlined by broken lines: *A*, Agua Dulce; *S*, Saxet, with recent extension; *W*, White Point. Wells in extreme northwestern margin of area are below Lissie. Wells in dune sand area are shallow and completed in dune sand or in latest Beaumont saturated by surface water from the dune sand.

SUBSURFACE FORMATIONS

Table I shows the approximate thicknesses of the formations as recognized by the writer and by other geologists who have studied the oil and gas fields of the district. The so-called "Reynosa formation" has been divided between the Lissie and Lagarto in this section. A lack of subsurface markers makes the identification and delimiting of the formations somewhat vague, although the marine Oligocene is definitely identified and fairly well known.

The section is a preliminary attempt to recognize the formations of the area from drillers' logs and from a few determinations of Oligocene *Foraminifera*. Some of the facts in regard to two of the oil and gas fields have been published (**9**, **10**, Price, 1930, 1931).

TABLE I

GEOLOGIC SECTION FOR SAXET OIL AND GAS FIELD, CORPUS CHRISTI, TEXAS

Depths (Feet)	*Thickness (Feet)*	*Formations*	*Members*
300	300	Beaumont	
1,500	1,200	Lissie, etc.	
2,050	550	Lagarto	
2,700	650	Oakville	
4,560	1,900	Catahoula	
5,200	600	Marine, Middle Oligocene	*Discorbis* zone: top, 4,560. *Heterostegina* zone: top, 4,738
?	?	Frio	

STRUCTURE

The geophysical work done in the area seems to have fairly well eliminated the probability of the occurrence of shallow salt domes. From the logs of gas wells, Agua Dulce is seen to be a closed anticline with gentle flank dips in the upper beds which become steeper below but do not approach the steepness of salt-dome flank dips. Agua Dulce may have closure in the upper 400 feet of Lissie sands. White Point is less well known structurally, but seems to have closure. The area of the gas field has gentle dips, though dry holes and old wells around the flanks suggest steeper dips and closure. The Saxet field seems to be an eastward-sloping nose. Closure, if existing, is not yet demonstrated by drilling. No steep dips are indicated by the well logs. The structure in the very shallow sands is not known. Faulting may be present.

Faulting has not been demonstrated in the area of Figure 1, but is reported at some of the producing fields of the Refugio area on the north and in Duval and Jim Wells counties on the west.

WELL WATERS

The writer and assistants conducted a survey of well waters of San Patricio and Nueces counties in 1930.

In the dune-sand belt along the inner shore of the coastal lagoon, wells obtain fresh waters with no taste of minerals from the dune sand at its contact with Beaumont clay, and from sand lenses in the Beaumont when they have been invaded by rain water caught by the dune sand. This fresh water is obtained at depths ranging from 75 to 100 feet. The full depth of the penetration of this surface water into the Beaumont is not known. The approximate range of dissolved substances in parts per 1,000,000 in the water from wells in the dune-sand area is shown in Table II. Only the radicals shown were determined.

TABLE II

DUNE-SAND WATERS

Parts per 1,000,000 by Weight

Cl	SO_4	$CO_3 + HCO_3$
120 to 650	Trace	230 to 525

In wells at depths ranging from 50 to 100 feet in the area of the Beaumont outcrop, fresh water is obtained under sandy soil, as a rule, and brackish waters under clay soils. In wells ranging from 100 to 1,000 feet deep, most of which do not go below 600 feet, non-brackish water is scarce. Some shallow sand lenses less than 200 or 300 feet deep seem somewhat generally to be more brackish than the waters from these depths down to 1,000 feet. No deep, non-brackish waters below 1,000 feet are known to the writer in this district and no artesian waters above 1,000 feet. Farther north, some areas of potable artesian water are known and farther south, where dune sand is widespread, fresh waters are more common (**12**, Taylor, 1907).

The approximate range of the dissolved substances in water from sands ranging from 100 to 1,000 feet in depth from the Beaumont and Lissie formations is shown in Table III.

TABLE III

LISSIE-BEAUMONT WATERS

Parts per 1,000,000 by Weight

	Cl	SO_4	$CO_3 + HCO_3$
San Patricio County	200 to 4,335	Trace to 150	180 to 550
Nueces County	200 to 3,500	200 to 2,350	140 to 900

The extreme high figures are obtained from isolated wells or small areas. The large majority of the determinations of chlorine are below 1,000, of sulphate below 500, and of carbonates below 400.

Well waters of sands which seem to be of the Lagarto are known from only a few wells. These sands lie just below the sands referred to the Lissie. The few wells studied which seem to be from this formation have the range of dissolved substances shown in Table IV.

TABLE IV

LAGARTO WATERS

Parts per 1,000,000 by Weight

Cl	SO_4	$CO_3 + HCO_3$
250 to 1,000	Trace to 400	200 to 500

WATER SANDS

The absence of well logs and of all reliable records of the depths to the top of water sands or total depths of the water wells makes any generalization on this subject impossible. From the absence of artesian flow in the area, it is to be assumed that the outcropping sand lenses are of short length down-dip and that water does not readily penetrate into the main body of the formation from the outcrop. That the shallower lenses receive surface waters is shown by the freshness of most waters down to 100 feet below the surface under sandy soils.

The interpretation of Versluys (**14**, 1931) of the presence of fresh waters beneath sand bars along a coast by downward penetration of fresh water in an area of sediments previously invaded by brackish water, seems to picture the conditions along the coastal dune-sand ridge of the Corpus Christi area.

From considerations brought out in the discussions of the relation of the shallow oil showings to structure, it seems that there may be some down-dip movement of the waters in some lenses and areas, although other factors may have caused the observed distribution of the oil.

SEEPAGES OF OIL AND GAS

The area seems to be much freer from gas seepages than coastal areas farther north in the Houston and New Orleans districts. Gas seeps were known at Refugio and at White Point before these fields were drilled. Gas was reported issuing from fissures in dry surface clay on Pintas Creek south of the Agua Dulce field and northwest of it on a branch of Agua Dulce Creek. In both places the gas seen was sighted at

fissures formed in Beaumont clay during the drought of 1916, 1917, and 1918. The greater number of gas "seepages" farther north may, in reality, be partly due to the relative scarcity of marsh gas in this district where there is not much standing fresh water. Marsh gas does not seem to have been observed along the Texas and Louisiana Gulf Coast as commonly in salt or brackish waters as in fresh waters. Whether this is a scarcity in fact or in observation is not known. Paraffine earth, a soil condition associated with gas seepages, is notably absent in this district.

The only oil seepages reliably reported in this part of the coast country are at St. Joseph's Island, where "live" oil has been seen by reliable observers seeping both through the ground of the island and near shore in the gulf and in the lagoon. St. Joseph's Island is a part of the offshore bar and is just north of Mustang Island.

Large amounts of asphalt have long been known along the shore lines, beaches, and islands of the Gulf of Mexico. This occurrence is commonly believed to have been seen by many before the marine transportation of petroleum in bulk began. The Indians who camped along the local shore lines had asphalt and used it in waterproofing and decorating pottery, as has been proved by extensive local archeological surveys (**5**, **6**, **7**, Martin, 1929, 1930). If waste oil from ships is discharged into the gulf waters near shore, it quickly becomes absorbed by the bottom sediments in shallow water. From the large amount of asphalt found along the gulf shore lines, it would seem that seepages of oil may be more common in the coastal waters than they have been observed to be in near-by land areas.

SHALLOW OIL OCCURRENCES

The minute amounts of oil from the water wells, which are the subject of this paper, are not noticeable in the returns (circulating mud fluid) from drilling wells or in the core samples of the formations. Table V shows the shallower occurrences of oil in the area, found in sufficient quantity to be noticed and recorded as showings in drilling wells for oil and gas or in quantity sufficient to make semi-commercial production.

TABLE V

SHALLOW OIL

Showings	*Feet*	*Semi-Commercial or Commercial Production*	*Feet*
White Point	1,025	Kingsville	2,100
Saxet	1,400	Refugio	3,700
		Agua Dulce	4,000
		Saxet	4,050
		White Point	4,900

SHALLOW GAS OCCURRENCES

The shallower occurrences of gas in wells drilled in the area are shown in Table VI.

TABLE VI

SHALLOW GAS

Showings	*Feet*
San Patricio County	
Generally in NE. quarter, below	100
In water wells, to	1,000
Kingsville, in an oil test well	100
White Point	400
Commercial Production	
Refugio	1,500
Saxet	1,650
White Point	1,850

DISTRIBUTION OF WATER WELLS

Blank areas on the map (Fig. 1) represent several classes: (1) areas where cisterns are in use because of non-potable waters found in wells drilled but now abandoned; (2) areas without water wells (houses supplied from near-by towns); (3) areas not reached in the survey; (4) areas of shallow wells in dune-sand belts; and (5) areas where wells are completed in the Lagarto formation.

In Class 1 are the White Point area and that south of the town of Corpus Christi; in Classes 2 and 3 are the broad zone west of Corpus Christi and south of Nueces Bay and Nueces River, which forms the Nueces-San Patricio county boundary, and a belt 6 miles north of White Point; in Class 3 are the Welder Ranch, the northwest corner of Nueces County, and the adjacent part of San Patricio County; in Class 4 is the belt along the west shore of the coastal lagoon; and in Class 5 are the northwest corner of San Patricio County and the southeast corner of Nueces County.

A larger percentage of the water wells of the area were visited in San Patricio County than in Nueces County.

EQUIPMENT OF WATER WELLS

All the wells visited were cased with cast-iron pipe. Nearly all were pumped by windmills, a very few by gasoline engines, and one, formerly equipped for windmill pumping, was operated by hand. No shallow dug wells were found. All wells had tanks for storage. At a few wells, there was no wind blowing at the time of the visit, and water could not be drawn direct from the well. Samples of water from most of the tanks showed

high salinity due to evaporation and consequent concentration of dissolved salts in the tank. Windmills are greased at irregular intervals. When new pipe or rods are placed in the well, some oil and grease are usually used. Where there was excessive recent oiling of any part of the equipment, water samples were not used in the study.

OIL IN PLEISTOCENE WATER SANDS

OCCURRENCE OF GLOBULES OF OIL

When 2-gallon samples of water are taken from the wells shown by dots in Figure 1, and the surface of the water is carefully and steadily observed, minute globules of oil can be seen to rise to the surface and to spread out into films with diameters commonly ranging from 1 millimeter to 3 or 4 millimeters. The observation is best made in a white enamel-ware bucket and with the light of the north sky reflected into the eye of the observer. Once seen, less precision of observation is needed when visiting additional wells. Some globules will not rise for 10-30 seconds after the bucket is drawn.

The films were observed under a microscope with difficulty, because of the rotary motion of the water in the bucket which could not be overcome during the period of observation except when the oil formed solid, brittle film. As the film of a globule spread on the water surface, before it evaporated or became brittle and lost its liquid content, three or four or more minute hemispherical protuberances were commonly noticed, the whole surface being iridescent. These protuberances were somewhat symmetrically arranged on the surface of the film formed from a single globule.

It was impossible to observe, because of the motion of the water, whether the films disappeared most rapidly around the edges, as though by solution, or from the center, as though by evaporation. This observation was prevented by the constant shrinking accompanying elongation of the globule as it rotated with the bucket. After a few rotations, the film of the more fluid oils takes the form of a long, thin streak, or, in the oils which have a more brittle film, it takes the form of a row of tiny dots. Other films become brittle as soon as they spread on the water and do not diminish in size.

Oil is commonly not seen in all samples taken. There seems to be a connection, in any well, between the showing of the oil and the time the sample is taken relative to the immediate prior use of the well. In some wells, water from the top of the column standing in the well yields oil, if the well has not been in use for several hours, though no oil shows

after this is drawn off. Certain wells show the oil only, or best, after violent or continuous pumping. In a few of the latter group, the oil did not show until silty sand began to appear with the water.[1]

MINUTE AMOUNTS OF OIL PRESENT

In one well only, in the Corpus Christi area, was enough oil obtained to yield an ether test. In this well there was much more oil in the water than in any other well visited, and the occurrence, though it seems otherwise comparable, can not, because of the volume of the oil, be considered typical. In this sample, a distinct ring of oil globules was left in the evaporating dish after extraction with ether and evaporation. This single well was at an abandoned farm house and the recent history of the well was not known. It is possible that oil had been poured into this well.

Oil was also extracted with ether from a well at Rosenberg, Fort Bend County, near Houston, where it occurred more plentifully than in the Corpus Christi area.

A. J. Hartsook, professor of chemical engineering at the Rice Institute, Houston, reported on samples collected by the writer. From an Erhelenmeyer flask sample (approximately 350 cubic centimeters) of oil film concentrated from many bucket samples and bottled with ether (amount not measured but approximately 75 cubic centimeters) Hartsook weighed 0.0517 gram of an oily residue after evaporation of 25 cubic centimeters of the ether-oil-water mixture.

From a 5-gallon sample of water taken direct from the well without concentration and shaken and bottled with ether (probably 170 cubic centimeters), Hartsook weighed 0.0021 gram from 25 cubic centimeters of the ether, or approximately one part in 3,000,000 of water by weight.[2]

The Rosenberg well showed many times more oil than the average well in the Corpus Christi area. The sample represented the water standing in the pipe after several buckets had been drawn. Though the concentration calculated is only approximate, it seems probable that the figures illustrate the order of magnitude of the occurrence and that the oil in the water from the wells in the Corpus Christi area occurs in about 1 part to 100,000,000 of water by weight.

[1]At several wells, red clay was present in this sediment. In the sample examined microscopically, this was not the reddish iron precipitate noted by Collins and Howard as occurring in water containing more than 0.1 part per 1,000,000 of iron, "Chemical Character of the Waters of Florida," *U. S. Geol. Survey Water-Supply Paper 596-g*, p. 181.

[2]Commercial ether (Squibb's) was used. Such ether contains a small quantity of dissolved solid matter which, if taken into account, would show a slightly smaller concentration of oil than the foregoing.

BRITTLE FILM FROM PETROLEUM

The globules observed are distinctly fluid and form an iridescent film, which, in some places, becomes brittle in a very short time after exposure to air on the surface of the water. The oil observed in the Corpus Christi area seems to be clear and colorless, or nearly so.

It is a belief commonly held by field geologists that brittle film does not form from petroleum. The unqualified statement that brittle film on water is formed by oxides of iron is common in text books of oil geology. Emmons (**3**, 1931, p. 11) states:

> Many oil seeps are associated with springs of water. In some there is merely a slight iridescent film or "rainbow" of oil above the water. Such a film resembles somewhat the film of iron oxide that covers some pools of water, and iron oxide films have been mistaken for oil films. The iron oxide film differs from the oil film, however, in that it is brittle and will break if the water is agitated, *whereas oil film will not.*[1]

This statement that oil film is not brittle is probably correctly applicable if the oil seen does not contain wax, or has not had time to evaporate since reaching the surface of the water, or where it occurs in considerable quantity so that any waxy residue is carried to the peripheral parts of the film and is not noticed.

Films of light, volatile oils containing wax in solution may become brittle and lose their ability to flow in a few seconds or minutes after their formation. The iridescence of the film may disappear with the evaporation of the more volatile constituents and the appearance of the solid wax, or it may be retained.[2]

If the seepage of oil is continuous, the observer might attribute the fresh oil to petroleum, but erroneously assume that the brittle film was formed by associated iron oxides. If the issuance of the fluids is intermittent, as is true of many seepages of oil, gas, and water, only brittle film may be noticed during a short period of observation, though "live oil" could be seen at other times.

Films from hydrated iron oxides are formed from reddish brown or yellow flocculent precipitates. The latter are not oils. When thick, they are opaque. All the brittle films observed in the water from the wells visited were formed from globules of a clear oily liquid.

[1]Italics are the writer's.

[2]The conclusion that a wax content is the cause of the film and will without exception show brittle film on evaporation is by inference and has not been experimentally investigated.

Thin brittle films are formed on the surface of stagnant or slowly moving bodies of fresh water by fine dust or clay blown over the surface of the water by the wind. This may be readily distinguished from the brittle film of waxy oils by the difference in texture of the film, that from oil being flaky and tabular and that from dust having a windrow texture of very fine parallel wrinkles. Its slight iridescence is that of a mechanical grating structure rather than that of a liquid.

REFERENCE OF OIL TO PETROLEUM

There seem to be no known oils other than petroleum which occur in sedimentary strata. Some organic sulphur compounds are said to be oils under atmospheric conditions. As these sulphur compounds commonly occur with petroleum, for the purposes of this study they may be considered as an integral part of petroleum.

Iron and manganese, which occur plentifully in the strata as lower oxides which are solids, form higher oxides which are oils, but these are unstable and exist only at high temperatures and pressures.[1] There seems to be no other conclusion than that the minute globules observed are petroleum.

CONTAMINATION PROBABLY ELIMINATED

Contamination of the water standing in the well by lubricating oils and greases used on windmill, casing, or pump-rods must be considered as a possible explanation of the occurrences. The uniformly minute size of the globules, the clean appearance of the oil film, the absence in it of dark centers common to used lubricating oil, and its high fluidity and high (Bé.) gravity, do not agree with such an origin by contamination.

Strong supporting evidence that the oil is not from lubricating oils lies in its widespread occurrence in water from Beaumont and Lissie sands and its absence at similarly equipped wells pumping water from dune sand (and highest Beaumont invaded by surface water) and from sands below the Lissie. Though many Beaumont and Lissie wells were examined for oil (1,187), and oil found in 29 per cent (311), and only a few wells from other formations were examined (50 in dune-sand ridge,[2]

[1] Mn_2O_7 is a brownish green, oily liquid which is violently explosive under atmospheric conditions, releasing oxygen in the presence of oxidizable substances. Iron has a somewhat similar high oxide.

[2] Some of these wells, as previously noted, were completed in sands in the highest Beaumont beneath dune sand. The dune sand collects rain water which, under slight hydrostatic head, penetrates a short distance vertically into the underlying sand and clay, displacing or diluting their previously contained water.

40 probably in Lagarto), no oil whatever was noticed outside the main body of the Beaumont and Lissie sands. The water wells and their equipment are of the same types in the three contiguous areas. Contamination present in one group should likewise occur from similar causes in wells in all three groups. This negative proof is not complete, because of the smaller number of wells visited in the dune sand and Lagarto. The survey was ended before the full significance of the absence of oil in these formations was noticed. The negative evidence, however, taken with the absence of any visible appearance of used oil in the wells studied, is believed to support the conclusion that the oil taken from wells is "live" and occurs in the water sands. The many observations, their widespread occurrence, and the differing depths of the wells preclude the assumption that the oil entered the sands or wells through the ground from storage tanks, pipe lines, or oil and gas wells.

Further argument against a lubricating-oil source is afforded by the experience with wells which had lately been greased. Except where there was excessive and very recent use of lubricating oil at the well, the oil showed in nearly the same percentage of recently oiled wells as in wells not oiled for many months past.

In some wells, oil not noticed by one observer was seen later by another. A few wells where it once showed did not yield oil when visited a year later.

BRITTLE FILM ALSO FORMED BY TERPENE

Oil having the characteristic odor and other physical properties of Gulf Coast terpene has been observed to have a brittle film. A reddish, brittle film was seen on salt water from the "2,700-foot gas sand" in the Crane No. 1 gas well of the Jackson County Oil Syndicate in the Horseshoe Lake area, Edna gas field, Jackson County. The salt water had stood several hours in a ditch before the film was noticed. This well and others in the same sand produced no gasoline and no oil with the gas except terpene.

In at least one other well reddish, brittle film was noticed by the writer outside the Corpus Christi district. This was a shallow water well in the hamlet of Hankamer, Chambers County, Texas, 2 or 3 miles south of the present oil field of Hankamer in Liberty County. The oil occurrence was nearly as strong as that of the Rosenberg well previously described and the film was brittle and iridescent. These two occurrences may be associated with structural features.

OIL GLOBULES PROBABLY TERPENE

The common and widespread occurrence of terpene in the shallow gas sands of the Gulf Coast, and the seeming absence of other oils in

TABLE VII

STATISTICAL SUMMARY OF OIL OCCURRENCES

	Number of Wells		
	Nueces County	*San Patricio County*	*Total*
Wells visited*	575	828	1,403
Not examined for oil	45	81	126
Examined for oil in whole area	530	747	1,277
Examined for oil in Beaumont and Lissie sands	530	657	1,187
Oil observed in well	113	198	311
Oil observed in tank only	12	20	32
Oil in well, tank, or both (sum)†	125	218	343
No oil seen when visited	405	529	934
Wells with sulphur (free or H_2S)	3	150	153
Wells with both sulphur and oil	3	98	101

	Percentages (Includes oil in tank)		
	Nueces County	*San Patricio County*	*Average*
Oil occurrence in wells examined for oil†	24	29	27
Same, omitting wells in dune-sand area and Lagarto	24	33	29
Absence of oil, in wells examined for oil	76	71	73
Occurrence of sulphur, in wells visited	0.4	18	
Wells with oil and sulphur, to wells with sulphur	100	65	
Wells with oil and sulphur, to wells with oil	2.4	45	
Wells with oil and sulphur, to wells examined for oil	0.5	13	
Range of depths of wells in feet	100 to 1,000	75 to 500	

Both Counties	*Number of Wells*		*Per Cent of Wells Tested for Oil*	
	Whole Area	*Omitting Dune Sand and Lagarto Wells*	*Whole Area*	*Omitting Dune Sand and Lagarto Wells*
Total wells visited	1,403	1,308		
Wells tested for oil	1,277	1,187		
Oil observed in well	311	311		
Oil observed in tank	32	32		
Oil in well, tank, or both†	343	343	27	29
No oil seen	934	844	73	71

*Formations: Lissie and Beaumont, in both counties; dune sand and underlying Beaumont in San Patricio, 50 wells; Lagarto (?) in San Patricio, 40 wells.

†Probably a significantly larger number of wells would show oil if visited more often. This is evidenced by the many wells in which oil was seen on a second visit, though not found at first.

such shallow sands in fields of the Coast Prairie (Beaumont outcrop) except over shallow salt domes, suggest that the oil globules in the shallow water sands of the Corpus Christi area as described herein, are also terpene.

No definite evidence of this determination can be presented at this time. The oil in the water sands is not found in large enough amounts for its odor to be detected. The brittle film common to some occurrences of both this oil and terpene does not prove their identity, but merely that both are light volatile oils and may contain enough wax to form a brittle film.

TERPENE

The writer has previously noticed the occurrence with natural gas and oil in the Gulf Coast region of the light condensate commonly called terpene (8, Price, 1926). The earlier chemical work on Gulf Coast terpene samples seems to have been inconclusive as to the composition of the oil. Physically, it has the properties of a high-test kerosene from asphalt-base petroleum. The gravity ranges, in 4 samples determined, from 26.4° to 34.3° Bé. at 60° F., or from 0.8535 to 0.8961 specific gravity. The odor of the samples in an extensive series examined[1] ranges from that of turpentine to a cedar odor. Terpene seems to be characteristic of the Gulf Coast Tertiary oils, being more prominent, by odor, in the shallower oils, but occurring with many grades of oil at different depths. One occurrence in a Texas Cretaceous oil has been reported. Its composition is probably variable. At least two hydrocarbon series have been reported as occurring in it.[2] It imparts the characteristic odor to the Gulf Coast natural gas of the Oakville and Catahoula sands, and of shallower formations. In many gas sands no other oil is present and the terpene condenses from a gaseous state when the temperature is suddenly reduced, as by expansion in separators designed to remove water and terpene from the gas. The terpene is not known in gas in larger amounts than approximately 1 barrel per 1,000,000 cubic feet. It does not commonly occur in noticeable amount in all gas wells of the area. An ordinary amount in the Corpus Christi area is 1 gallon of terpene per 1,000,000 cubic feet. A typical occurrence at Saxet ranges from 15 to 100 parts per 1,000,000 relative to salt water made by the well.

The only oil known to the writer to occur in the immediate coastal belt with the natural gas from the formations above the Oakville and

[1]Oils from Gulf Coast Tertiary sands, from the Eocene to the Pliocene, both from shallow and deep oil sands and from outcrops of the Jackson in Texas, and an outcrop seepage from the Tertiary of Alaska, have been examined. The well samples were studied in the laboratory of the Humble Oil and Refining Company in Houston. Paul Weaver reports aromatic oils in Tabasco, Mexico, and from Tertiary outcrops on Sakhalin Peninsula north of Japan which seem to be similar to terpene.

[2]By Nicholas Cheronis, chemist, of Chicago, Illinois. Based on uncompleted examination of terpene from Edna, Jackson County, Texas.

Catahoula is this so-called terpene. Gasoline and petroleum constituents other than terpene have not been reported at depths less than 3,000 feet, although some of the reported showings of dark oil at shallow depths may contain fractions other than terpene. The assumption is that the minute globules in the Lissie and Beaumont are probably terpene.

With this interpretation, terpene may be described as a light, volatile, aromatic oil occurring with petroleum and natural gas, to which it imparts an odor of turpentine or cedar. It ranges from 0.8535 to 0.8961 in specific gravity and from 26.4° to 34.3° Bé. gravity at 60° F. Its color ranges from pale straw-yellow, through deep cherry-red to dark green. The darker shades may be due to admixture with other crude oils. Its film may range from brittle to waxy, colorless to red, but always iridescent except when only the wax remains. It seems to be found without associated oils in the shallow water and gas sands of the Gulf Coast of Texas and Louisiana. It occurs in large amounts with some of the shallow, cap-rock oils on salt domes, as at Humble and on several Louisiana coastal domes.[1] It is also present, probably in relatively smaller percentages, in many of the deep oils of the Tertiary, and has been reported from a Pennsylvanian limestone.[2] It is probably related to the terpenes of Europe and Asia, but the composition of the various terpenes, if fully known to chemists, is not yet published, so far as the writer is aware.

A partial bibliography of terpene is given at the end of this article.

ASSOCIATION OF OIL OCCURRENCES WITH FREE SULPHUR

The association of sulphur compounds with many petroleums probably begins at the time of the original deposition of the source beds. Trask, referring to material examined by him in his extensive search of modern sediments for evidences of petroleum, has shown (**13**, Trask, 1930) that "free sulphur is a common minor component of all the [modern] sediments."

In San Patricio County, 150 wells, or 18 per cent of those examined, showed free sulphur or hydrogen sulphide. Of these 150 wells, 98, or 65 per cent, showed both sulphur or hydrogen sulphide and oil. The wells showing free sulphur occurred in a part of San Patricio County in

[1]Lee Hager states it as his experience that if terpene is found in large amount in an oil sand, it indicates much water near by in the sand. Oral communication. In gas wells it seems to occur both above the water and in the water-bearing levels in the sand lenses.

[2]D. S. Hager reports it from Caddo limestone, 6 miles south of Bangs, Brown County, Texas, from a well of the Janellen Oil Company, at 1,100-1,200 feet in depth.

which nearly all wells showed it, the water, in some wells, being as black as ink. In very few wells in Nueces County were either free sulphur or hydrogen sulphide noticed.

Ether dissolves free sulphur as well as oil. In making the ether tests on water, the residue was examined visually for oil globules. Equivalent samples of the commercial ether used were also evaporated unmixed with well water, but showed no oily residues.

AREAL DISTRIBUTION OF DISSEMINATED OIL IN SURVEYED AREA

Figure 1 shows the distribution of water wells examined for oil. The outlines of the producing oil and gas areas on three proved, but incompletely known "structures"[1] are shown. Other possible "structures," as yet untested for oil and gas, occur in the area, but are not yet proved by drilling.

Large areas near the coast of the coastal lagoon, with the exception of a 3- or 4-mile strip nearest the water, overlain by 20-30 feet of dune sand, have few wells because of the strong salinity of the water at all depths. Areas along Nueces River, which forms the boundary between San Patricio and Nueces counties, are served with river water, as is a large area around the city of Corpus Christi. Other large blank areas on the map were either served from town water systems or were not reached in the survey. The areas not reached lie in the northwest parts of San Patricio and Nueces counties.

Fewer water wells were visited in Nueces County than in San Patricio County.

It has been noted in previous paragraphs that the dune-sand area along the coast, which is coincident with Live Oak and Flour Bluff ridges, contains shallow wells completed in the dune sand, or in sand below which water from the dune sand has invaded, displacing the salt water. As has been shown, these wells yield water of very low mineral content, in strong contrast with the water from the deeper wells. The salinity of the deeper waters, as shown in Tables II, III, and IV, ranges commonly from 300 to 3,000 parts per 1,000,000 for the chlorine radicle. In San Patricio County, the sulphate radicle was low or only a trace was present. In Nueces County, the sum of the sulphate radicle plus the

[1]By "structure" is meant a local deformation of strata caused by folding or faulting, resulting in the formation of traps favorable for the accumulation of oil and gas in commercial amounts. "Structures" in this area seem to be gentle noses, probably faulted, some possibly having closure without faulting.

carbonate radicle was commonly approximately equal in amount to the chlorine radicle.

The dune-sand area yielded no oil showings. It has not been surveyed as a whole. Wells visited which pumped water from Lagarto (?) sands below the Lissie are shown in two small groups at the northwest edge of the surveyed area. These number forty-four and showed no oil (forty examined for oil).

The map shows the oil occurrences to be widespread and essentially continuous in the areas of wells pumping from the Beaumont and Lissie west of the coastal dune sand.

RELATION OF OIL TO STRUCTURE

IN SURVEYED AREA

The blank spaces in the map show that the survey is not sufficiently complete either to establish a connection of the oil occurrences with "structure," or a lack of such a connection. At White Point there are very few wells because of the strong salinity of the water. At Saxet both strong salinity and the availability of the city water mains causes a lack of wells. At Agua Dulce there is a possible structural influence revealed in the pattern of the oil occurrences. Oil occurs on the "structure" and at the west, but less plentifully or not at all in wells on the east side. This type of occurrence suggests a fault on the east side of Agua Dulce acted as a barrier to down-dip flow of water and oil, and that some of the water sands derive water from the surface water table. However, the wells visited in Nueces County are not plentiful enough to eliminate chance groupings and the limits of the known and suspected structures are too imperfectly defined for conclusions to be drawn.

There is, therefore, only a suggested relation of the oil occurrences to structure. Continuous lines of oil occurrences in San Patricio County indicate a somewhat uniform dissemination both on and off "structure."

Although there are no water wells in some areas, the extension of this survey to every water well in the two counties might yield evidence as to the structural relations of the occurrence. Lenticularity of the water sands would complicate any conclusion as to structural relations.

SOME CONTRASTS BETWEEN HOUSTON AND CORPUS CHRISTI DISTRICTS

Before consideration is given the origin of the disseminated oil of the water sands of the Corpus Christi area, the contrasts should be reviewed between this area and the more fully developed oil district

north and east in Louisiana and Texas, where, within the area of the outcrop of the Beaumont and Lissie formations, shallow salt domes and salt domes of intermediate depth are the predominant structures developed. These older areas are referred to collectively as the Houston district.

The Houston district is better known than the Corpus Christi area, has been more thoroughly prospected, and its fields more fully developed. It contains several shallow salt domes where oil occurs in commercial pools in super-cap and super-salt sands. On some of these domes there are shallow oil pools in sands of the Lissie-Beaumont group. If this statement were allowed to stand unqualified, there would seem to be a marked contrast in the oil content of the shallow sands of the two areas, no shallow oil having been produced to date in the Corpus Christi area. However, there is much information to be gained before such a comparison can be made on equal grounds.

The Houston district has not been studied for disseminated oil in water sands off "structure." The writer has observed it at isolated localities on, or adjacent to, known or supposed salt domes or uplifted "structures." The Corpus Christi area, however, has not been prospected for oil and gas fields nearly so thoroughly as has the Houston district. It would be possible to select many salt domes in the Houston district where shallow oil is not known in the wells so far drilled. The number of such domes exceeds the total number of drilled structures in the Corpus Christi area. The Palangana and Piedras Pintas salt domes of Duval County are not considered in this discussion because they are situated inland from the Beaumont or Lissie outcrops.

With this background of unequal information in mind, we may better consider the bearing of the differences of oil and gas occurrence and of structure in the two areas on problems of origin and migration.

The shallowest production in the Corpus Christi area is of natural gas, which is practically pure methane (analyses commonly showing 99.2 per cent methane), with no ethane, propane, or butane and no gasoline, but with small amounts of volatilized terpene in all the shallower gas sands. This blanket of commercial gas on "structure" without oil and lying above the commercial oil sands, is not found in the Houston district. Terpene occurs in the shallow oils of the Houston district, but mixed with larger amounts of other petroleums.

Though small gas seepages are recorded as seen in the early days of development at Refugio and White Point, gas seepages are not commonly thought of as characteristic of the Corpus Christi area. Paraffine earth,

which is commonly found in the soil at gas seeps of the Houston district, seems to be absent in the Corpus Christi area. Only one oil seep in the Corpus Christi area is known to the writer. Oil seeps are more plentiful in the Houston district.

Faulting is known to be present on salt domes and is probably much more common than has been observed. Faulting is present just west of the Corpus Christi area and may occur in it, the presence and amount of faulting here not as yet having been demonstrated.

The amount of closure and the steepness of flank dips are greater in the salt-dome fields of the Houston district than in the fields of the Corpus Christi area, where, if salt is present beneath the drilled "structures," it lies at great depths and has not sharply domed the overlying beds. The imperfectly prospected Gyp Hill near Falfurrias may be a salt dome, but its lack of development eliminates it from consideration.

The minute amounts of oil in the Beaumont and Lissie sands of the Corpus Christi area, here reported, seem wholly inadequate to form a source for commercial accumulations of petroleum even in the presence of good closure and steep flank dips such as occur above shallow salt intrusions. In the shallow oil pools of the Houston district are found typical crude oils, but the oil films of the Corpus Christi shallow sands seem to be from lighter oil; probably, as has been pointed out, terpene.

ORIGIN OF OIL

ALTERNATIVE INTERPRETATIONS

Several alternatives are available in the attempt to explain the minute oil globules and the seeming lack of commercial pools in the shallow sands at Corpus Christi, as contrasted with the commercial oil pools in beds of approximately equivalent age in the Houston district.

1. Source beds of the later formations are richer in the Houston district than in the Corpus Christi area; or

2. If source beds are equally developed and equally rich in the shallow formations in the two areas (a topic not as yet investigated), the logical conclusion seems to be that (a) oil has not yet entered the sands in the Corpus Christi area, or (b) the covering clays of the Houston district are impervious, and those of the Corpus Christi district must be pervious (**11**, Price, 1931), allowing the oil and most of the gas to escape to the atmosphere as fast as it is developed.

3. If source beds are equally developed and rich and the oil has entered the sands in the one area but not in the other, it is necessary to look for a local agent operative in one but not in the other which has

caused the oil to enter the sands. Barton (**1**, 1931, p. 63) thinks there is only "a faint theoretical possibility of a slight (genetic) relation between salt domes and the formation of petroleum," basing this slender concession to such a view on the slightly higher subsurface temperatures found on some salt domes than in the surrounding beds off "structure."

4. The alternative which seems to present the least difficulty allows the postulation of a fairly uniform set of conditions in the two areas as to source beds, covering clays, and regional agents which may have been involved in the generation of petroleum from source beds. It is that vertical migration, which Barton says "seems definitely to have occurred on American salt domes" in the flank sediments of shallow domes, has also been the chief factor in the accumulation of shallow oil pools in cap and super-cap situations on shallow salt domes. With this view Barton does not agree, as he states that "localization of accumulation in super-cap (super-salt) sands is due to simple anticlinal trapping in sands under hydraulic head" and that vertical migration on the salt domes has been a minor factor.

Flank-sand accumulation and super-salt-sand accumulation on salt domes present marked structural environmental contrasts which emphasize the presence of faulting in the former situation and its seeming absence or inconspicuousness in the latter. A still greater contrast in regard to faulting and dip is presented between the salt-dome "structure" even in its shallowest oil sands, and the non-salt-dome "structures" of the Corpus Christi area.

The widespread, essentially uniform occurrence of the minute oil globules in the Corpus Christi area does not indicate that vertical migration of oil, as such, has occurred there. The seeming restriction of gas in notable amounts in water sands to the northeast part of San Patricio County and the adjacent part of Aransas County does not strengthen the view that upward migration of gas brought the oil (terpene ?) with it in a gaseous state. However, gas migrating upward might have for a time occupied part of the water sand and have later escaped, leaving some terpene in the water.

Though the oil globules were not noticed in areas on the east side of Agua Dulce and the Mud Flats structural prospect, these two examples are not sufficient to prove anything as to lateral migration or fault traps, because of the lack of control on the lenticularity of the sands and because of the limited number of known "structures" in the area which are adequately covered with water wells. Lateral migration in the sands, until fault planes (as yet unknown) along the east sides of these two areas interposed barriers, is, however, suggested.

LOCAL ORIGIN OF OIL POSTULATED

The data, although admittedly scanty in regard to important factors, suggest that vertical migration of oil into the Beaumont and Lissie sands of the Corpus Christi area has not occurred uniformly throughout the area, but that it has been the cause for commercial pools of oil in the same beds in the Houston district. A local origin for the minute oil globules in the Corpus Christi area is suggested by the information now available. By the term *local origin* is meant an origin in the water-sand group or in the immediately adjacent beds. It is plainly recognized, however, that the whole phenomenon may be merely an indication of the upward migration of small amounts of natural gas bearing terpene.

MOST RECENT FORMATION OF PETROLEUM

An important approach to the problem of the origin of petroleum is a search for the most recently formed deposits. In this problem, even the smallest amounts of oil become significant. Although a distinction is to be made in any inquiry into the mode of formation of commercial pools of petroleum between its occurrence in minute traces and in larger amounts, yet the formation and appearance of minute traces of oil may herald the later generation of commercial amounts from the same deposits. If this disseminated oil of the shallow water sands is terpene, or any light constituent of the Gulf Coast crudes, rather than a typical crude oil, and if it had a local origin, its mode of formation might be more readily studied and inferred from its physical environment and geologic history than that of a more complex mixture. Turpene might, thus, be formed here before the formation of natural gas in the same bed.

Trask, in his preliminary survey of the ocean bottoms for evidences of petroleum in basins of present deposition, states (**13**, Trask, 1930, p. 1451):

> Liquid petroleum probably does not occur in sediments at the time of their deposition. . . .if it is present, it is in very small amounts. Petroleum present in newly-deposited sediments is not an important factor in the genesis of oil. Presence of small quantities of solid paraffines suggests that some constituents of petroleum occur in fresh sediments.

Trask has stated to the writer[1] that his laboratory method would not have detected oil in such minute quantities as here described, and that he did not examine the sediments visually in water at the time of their collection. Hence, although Trask failed to find oil in sediments

[1]Oral communication.

from bays and lagoons in this area, it is not yet certain that the modern sediments here may not contain amounts of oil comparable with those of the Pleistocene.

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OIL-FIELD WATERS OF NORTH-CENTRAL TEXAS[1]

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ABSTRACT

The mapping of geological structure in north-central Texas is only slightly facilitated by the results derived from the study of oil-field waters. However, application of facts already known can be of much value in regions which contain salt domes, or faults, where strongly saline solutions may approach the surface and intermingle with fresh or slightly saline solutions, thus producing abnormal waters for short distances from such features.

Geochemical investigations were continued from July 1, 1930, to June 30, 1931, as part of Project 25-B of the American Petroleum Institute's research program. The object of this research is to analyze oil-field waters and to determine their relation to regional and local geological structure.

Oil-field water investigations were begun by the Institute during 1929 and carried on in conjunction with earth-temperature studies. The object at that time was to study the saline content of waters, the change of this content in relation to regional and local structures, and to learn, if possible, to what extent a change in the chemical content of the water was the cause for abnormal temperature gradients along faults and over salt domes.

The location of the area from which waters were collected during the present study is in north-central Texas, over the Red River uplift and the northern end of the Bend arch. The Gose oil-producing horizon situated directly beneath the Gunsight limestone and occupying nearly 80 feet of the Graham formation of the Cisco group of upper Pennsylvanian age, is the most important water-bearing formation investigated. This horizon was chosen because of its regional extent, and because it is penetrated by many wells. It crops out in the area examined as a sinuous band extending from the vicinity of South Bend, Young County,

[1]Manuscript received, February 5, 1932. This paper contains preliminary results of an investigation on "Underground Temperature in Oil Fields" listed as Project 25-B, Pt. 3, of the American Petroleum Institute research program. Financial assistance in this work has been received from a research fund of the American Petroleum Institute donated by John D. Rockefeller. This fund is being administered by the Institute with the coöperation of the Central Petroleum Committee of the National Research Council.

northeastward into Jack County. Beneath the surface it dips in a northwesterly direction, extending through the north half of Young County, all of Archer County, much of Wichita County, and into the adjoining counties on the east and west. This general dip is interrupted by an anticline over the Red River uplift which extends east and west through Wichita and Wilbarger counties. Several water samples were collected above the Gose horizon and from adjoining areas so that comparisons could be made.

The system of analysis followed is in general that outlined by Reistle and Lane.[1] The radicles estimated are calcium, magnesium, hydroxide, carbonate, bicarbonate, sulphate, and chloride. Sodium was not determined directly, but was calculated, as is usually done in the analysis of oil-field waters.

The results of the analyses show that near the outcrop of the Gose horizon, in a belt ranging from 10 to 20 miles in width, the total solids are very low, much of the water being potable. Salinity increases to several times that which is found in the present ocean in a belt ranging from 4 to 10 miles in width. Farther away it increases less markedly and reaches a maximum south of Electra of more than seven times that which is found in the present ocean. In general the salinity increases from the surface downward to the Gose horizon.

In the Turbeville and Harmel pools of Archer County all available wells were sampled and chlorides determined for any relation between chloride content and local structure. The variation in composition is so small and erratic that no definite conclusions can be drawn.

Saline deposits have not been found in the area underlain by the Gose sand, and the closest known are in the Permian basin nearly 100 miles west and stratigraphically many feet higher. Outcrops of the strata containing these waters are very fossiliferous. In addition, many fossils have been found down-dip in drill cuttings from rocks now containing very saline waters. As animals will not live in waters as saline as those analyzed, it is evident that these waters either have become more saline *in situ* or have migrated from an area of saline residues. An increase in salinity *in situ* is difficult to explain if saline residues are not present in adjoining rocks, as very few other sedimentary minerals contain chlorine. Hydration of minerals may account for a slight increase of salinity *in situ* by removal of water, thus increasing the concentration of that which remains. Optimum conditions for hydration of most minerals are found

[1] C. E. Reistle, Jr., and E. C. Lane, "A System of Analysis for Oil Field Waters," *U. S. Bur. Mines Tech. Paper 432* (1928).

during the period of weathering and transportation, and not after they are incorporated as sediments. Therefore, it is improbable that much water could be removed in this manner. Evaporation, the easiest way of concentrating water, can not act under this condition because of the depth to which these sediments are buried.

If the Permian basin has supplied these saline waters, processes such as compaction of sedimentary material and actual tilting of the basin may have been effective in forcing the contained waters outward along porous beds. The migration of water across beds into lower strata is difficult to explain, but this could be caused possibly by migration along faults and through interfingering porous zones.

The mapping of geological structure in north-central Texas is only slightly facilitated by the results derived from the study of oil-field waters. However, application of facts already known can be of much value in regions which contain salt domes, or faults, where strongly saline solutions may approach the surface and intermingle with fresh or slightly saline solutions, thus producing abnormal waters for short distances from such features.

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EARTH TEMPERATURES OF NORTH-CENTRAL TEXAS[1]

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ABSTRACT

Temperature gradients, consequently isothermal surfaces, in north-central Texas are controlled by the proximity of the pre-Cambrian rocks to the surface. Unconformities probably also affect temperature gradients only inasmuch as they present angular relationships with better conducting rocks beneath poorer conducting rocks, or under exceptional conditions the reverse may be true. The present study indicates that a feasible explanation for the variation of geothermal gradients over anticlinal structure is the difference in conduction of heat by rocks.

Geothermal investigations were continued from July 1, 1930, to June 30, 1931, as part of Project 25-B of the American Petroleum Institute's research program. The object of this research is to determine from temperature measurements in oil wells the shape of isothermal surfaces over buried ridges.

Temperature investigations were begun by the Institute nearly four years previous to the present work, and were undertaken because of observed variations in geothermal gradients that indicated a relation of geothermal gradients to geological structure. Isothermal surfaces are used here instead of geothermal gradients to depict the earth temperature conditions. An isothermal surface may be defined as an imaginary surface every point of which is at the same temperature.

The location of the area in which earth temperatures were measured is in north-central Texas over the Red River uplift and the northern end of the Bend arch. The Red River uplift extends east and west south of Red River in Wilbarger, Wichita, Clay, and Montague counties. The Permian surface sedimentary rocks dip gently away from this uplift, and those of Pennsylvanian and pre-Pennsylvanian age below the surface dip more steeply with depth. Beneath the Paleozoic rocks the pre-Cambrian complex composed of granite and various schistose and gneissic rocks has been penetrated by several wells. The Bend arch is a low,

[1]Manuscript received, February 5, 1932. This paper contains preliminary results of an investigation on "Underground Temperature in Oil Fields" listed as Project 25-B, Pt. 3, of the American Petroleum Institute research program. Financial assistance in this work has been received from a research fund of the American Petroleum Institute donated by John D. Rockefeller. This fund is being administered by the Institute with the coöperation of the Central Petroleum Committee of the National Research Council.

broad, plunging anticline that extends from the Central Mineral region of Texas northward, terminating near the north Archer County line immediately south of the Red River uplift.

The methods outlined by Van Orstrand[1] are used in obtaining earth temperatures. Oil-well maximum thermometers are lowered on piano wire from a hand reel over a measuring wheel which records the depth. For depths below 4,000 feet the thermometers are attached to the bailer and lowered on the sand line.

Wells in temperature equilibrium are scarce in this area, due either to escaping gas somewhere in the well, or to recent production of fluids. Thirty-three wells were tested and, although care was taken in selecting suitable wells, nearly 25 per cent were found to be out of temperature equilibrium. More valid conclusions could be made if more wells had been tested. Earth-temperature data were obtained from 13 wells in Wichita County, 8 in Montague County, and not more than 3 in any other county. Isothermal surfaces as located in these wells dip in the same general direction, but less steeply than do the sedimentary rocks except in two localities. One of these exceptions is found in the Nocona district, Montague County, where the 75° isothermal surface exceeds the dip of the "Big lime" by 100 feet in the same horizontal distance, and the other is in the Electra district, Wichita County, where the isothermal surfaces dip a little more steeply than does the Gunsight limestone.

The finding of isothermal surfaces that dip more steeply than do the enclosing sedimentary rocks is significant in that it limits the possibilities advanced for the interpretation of the variation of geothermal gradients. For example, it has been suggested that during deformation of the sedimentary rocks the isothermal surfaces were also deformed, and have not since come back to essentially a flat surface. If this were true, nowhere would the isothermal surfaces ever dip more steeply than the sediments with which they are associated.

Hydrostatic head causes fluids to move along porous strata traversing synclines and anticlines, and according to some authorities heat enough is carried along to produce the irregularities found in isothermal surfaces. With this condition, isothermal surfaces should dip less steeply than the strata on the side of the anticline from which the fluids approach, and could dip more steeply on the opposite side where the fluids are moving downward. As temperature measurements were obtained only on

[1] C. E. Van Orstrand, "Description of Apparatus for the Measurement of Temperatures in Deep Wells," also, "Some Suggestions in Regard to the Operation of the Apparatus, and Methods of Reduction and Verification of the Observations," *Amer. Petrol. Inst. Prod. Bull. 205* (1930), pp. 9-18.

parts of the "structures" showing the steeply dipping surfaces, the entire condition can not be depicted. However, one of these steeply dipping isothermal surfaces is located on the north side and the other on the south side of a buried ridge. The migration of fluids in these two localities, if controlled by regional structure and topography, should be in almost the same direction, thus causing the isothermal surfaces which dip more steeply than the strata to be on the same side of the buried ridges. This evidence, although not conclusive, supports the idea that migration of fluids is much too slow noticeably to alter temperature conditions over anticlinal structure.

No field evidence is available to show, as has been suggested, that chemical reactions cause variations in geothermal gradients. If the age of these sediments and the lack of marked deformation are considered, it seems that chemical equilibrium must have been reached long ago and heat thus created long since dissipated.

Many varieties of rock differ in their capacity for the conduction of heat. If two rock formations varying greatly in their ability to conduct heat were located side by side, undoubtedly isothermal surfaces passing from one to the other would be warped. As pre-Cambrian rocks of this district are dense, they are probably better conductors of heat than the overlying porous sedimentary rocks. If this be true, areas in which the pre-Cambrian approaches the surface, as in these buried ridges, afford a channel of better heat conduction; therefore, a higher gradient should be maintained in the overlying more poorly conducting sediments.

The foregoing is a very brief statement of facts and supposition, but perhaps enough is given to justify the conclusion that temperature gradients, consequently isothermal surfaces, in north-central Texas are controlled by the proximity of the pre-Cambrian rocks to the surface. Unconformities probably also affect temperature gradients only inasmuch as they present angular relationships with better conducting rocks beneath poorer conducting rocks, or under exceptional conditions the reverse may be true.

The present study indicates that a feasible explanation for the variation of geothermal gradients over anticlinal structure is the difference in conduction of heat by rocks. Migration of fluids, chemical reactions, and deformation of the isothermal surfaces at the time of folding with a lag in the recovery of temperature equilibrium seem to be of minor importance. Special conditions, however, must be considered. Radioactive substances produce heat beneath the earth's surface and could, if unequally distributed, produce a condition in which the isothermal surfaces

are warped, but it seems improbable that the distribution could be such that nearly all deformed isothermal surfaces would correspond with the structure of the rocks. Also, residual heat from geologically young igneous intrusions could produce isothermal surfaces that simulate the dip of the enclosing rocks.

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DISCUSSION

AGE OF PRODUCING HORIZON AT KETTLEMAN HILLS, CALIFORNIA

In recent articles appearing in the *Bulletin*, the following statements have appeared.

> The upper 700 feet of the known oil horizon at Kettleman Hills represents a sandy facies of the *Valvulineria californica* zone. All of this zone is established as being stratigraphically higher than the type Temblor, and represents the lower part of the type Monterey. The age of the basal several hundred feet of the oil horizon is at present indeterminate, but seems to be not older than upper Temblor.[1]
>
> Regional stratigraphic studies of the writer indicate that much of the main oil horizon at Kettleman Hills is not Temblor in age, as has commonly been supposed, but is the overlying lower member of the Monterey. Paul P. Goudkoff (April 23, 1931) informs the writer that paleontology and petrography lead to the same conclusion.[2]

California geologists are well aware that the opinions of Goudkoff and Eaton, here stated, are not accepted universally. In fact, there is ample evidence of the Temblor age of the upper part of the oil horizon of Kettleman Hills and considerable reason to believe that the lower part, as well, belongs to the Temblor formation.

The problem has more than academic interest because the agreement of the Kettleman North Dome Association contains many provisions stated in terms of the structural position of the top of the Temblor formation. Although not specified in the agreement, it is clear that the top of the Temblor formation was considered to be coincident with the top of the oil-producing zone. It is the conclusion of the writers that the two are coincident and that no ambiguity exists in the provisions of the agreement of the Association.

Goudkoff's table[3] indicates that he has accepted the top of the "Button bed" sandstone as the top of the Temblor. This follows the original definition of the formation by F. M. Anderson.[4]

In the first column of Table I, "Type Temblor (After May and Gilboe)," the *Valvulineria californica* zone is shown by Goudkoff as resting directly on the "Button bed" sandstone. However, May and Gilboe clearly recognize the presence of a shale interval between the base of the *Valvulineria californica*

[1] Paul P. Goudkoff, "Age of the Producing Horizon at Kettleman Hills, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 7 (July, 1931), pp. 839-42.

[2] J. Edmund Eaton, "Decline of Great Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 1 (January, 1932), footnote p. 27.

[3] *Op. cit.*, p. 841.

[4] F. M. Anderson, "Stratigraphic Study of the Mount Diablo Range, California," *Proc. California Acad. Sci.*, 3rd Ser., Vol. 2 (1905), No. 2, pp. 169-70.

TABLE I

REVISED CORRELATION FROM GOUDKOFF'S TABLE I. AUTHOR'S INTERPOLATIONS IN PARENTHESES

	Type Temblor (After May and Gilboe)	*Type Monterey*	*North Belridge*	*Feet*	*Lost Hills*	*Feet*	*Kettleman Hills*	*Feet*
MONTEREY	*Valvulineria californica* zone	*Valvulineria californica* zone	(Brown shale. *Valvulineria californica* zone assemblage. Material largely replaced by pyrite	50)	Brown shale. Arenaceous *Foraminifera*. A few fish remains		Brown shale. Arenaceous *Foraminifera*. A few fish remains. (Sporbo. Calcareous organisms not preserved.) (Sandy at base and with basal bed of well rounded, hard, dark-colored pebbles)	
	(1,125 feet thick in Chico-Martinez Creek—Goudkoff & Hughes)		(Hard dark brown shale. Arenaceous *Foraminifera* and "sporbo." Calcareous organisms not preserved	530)				
			Brown shale. Arenaceous *Foraminifera* and collophane oölites or so-called "sporbo"	170	(Absent)		(Absent)	
			Brown shale. Calcareous foraminiferal assemblages typical of the *Valvulineria californica* zone	60				
					(*Unconformity*)			
	("Monterey shale" between *V. californica* zone and "Button bed" sand) (Appropriately called Gould shale member of Temblor) (250 feet in Chico-Martinez Creek—Goudkoff & Hughes)	(Absent)	Brown shale grading to sandy shale. Barren of calcareous *Foraminifera*. Rich in "sporbo"	220	Brown shale grading to sandy shale. Rich in "sporbo." (Absent in crest wells)	300	Brown shale grading to sandy shale (and fine sandstone). Rich in "sporbo" (10-80) (*Occasional Pecten andersoni*)	

TABLE I—*Continued*

	Type Temblor (After May and Gilboe)	*Type Monterey*	*North Belridge* Feet	*Lost Hills* Feet	*Kettleman Hills* Feet
TEMBLOR	"Button bed" sandstone (174 feet) (Common *Pecten andersoni;* plentiful Scutella near base. 410 feet in Agua Media Creek) (Irregular sporadic shale beds) (Pholas borings at base in Carneros Creek. Angular unconformity at Devils Den)	(Absent)	Light gray, fine, arkosic sandstone. A small proportion of white clay matrix. (*Pecten andersoni, Turritella ocoyana,* and barnacle fragments.) .... 150 Same, containing *Pecten andersoni* and *Scutella* sp. ?) .... 10 Same, no fossils (*Pecten andersoni*) ...... 200 Brown shale, "identical with that above." *Valvulineria californica* assemblage. (Temblor *Foraminifera*) .... (50) (Basal bed of conglomerate with *Scutella merriami* and *Ostrea* sp.)	Light gray, fine arkosic sandstone. A small proportion of white clay matrix. (*Pecten andersoni* and barnacle fragments.) (Prominent beds of blue to brown shale in lower part) .... (400)	TOP OF OIL ZONE Light gray, fine, arkosic sandstone. A small proportion of white clay matrix. Alternates with irregular streaks of brown shale "identical with that above." The maximum thickness of this part of the oil zone is .... 700 (In crest wells .... 600) Gray, medium-grained, hard, calcareous sandstone. Small black pebbles. Fragments of pelecypods and of a *Turritella* sp. ? A poor micro-fauna in shaly streaks suggests age not older than upper Temblor .... (225)
	------(*Unconformity*)----- Shale, some sandstone ("Media shale") (450-490 feet) (Characteristic shale pelecypod fauna)		------------ (*Unconformity*) ------------ (Hard, dark gray to black shale. Temblor *Foraminifera* and characteristic shale pelecypod fauna .... 250)	—?——?——?— (Dark gray to black shale. Characteristic shale pelecypod fauna) .... (80-125)	(Dark gray to black shale with thin sandstone streaks. Base uniformly about 1,000 feet below top of sand in axial wells) .... (175)
	Carneros sandstone (*Scutella merriami*) (168 feet)		Gray, medium-grained, hard, calcareous sandstone. Small black pebbles. Fragments of pelecypods and gastropods. A poor micro-fauna in shaly streaks suggests (Temblor age)	(Green-gray sandstone and poorly sorted greenish gray sandy shale, dark blue-gray shale, gray shaly sandstone, streaks of black pebbles) .... (640)	(Green-gray sandstone, poorly sorted green-gray and variegated sandy shale .... (500)

zone and the top of the "Button bed" sandstone. In their unpublished manuscript[1] is contained the following statement.

> The Carneros member, Upper shale and Button bed of the type Temblor *and the overlying "Monterey shale" up to the base of the Valvulineria californica zone* are approximately equivalent to the beds lying between the Jewett sand and silt and the base of the *Valvulineria californica* zone on the east side of the San Joaquin Valley.

It has been demonstrated repeatedly that the base of the *Valvulineria californica* zone coincides with the base of the Monterey formation at its type locality. The presence of a shale member between the base of the *Valvulineria californica* zone and the top of the "Button bed" sandstone in the Carneros Creek outcrops is generally recognized. Furthermore, this shale member contains an assemblage of *Foraminifera* which is distinct from that of the *Valvulineria californica* zone. This assemblage is found elsewhere in the San Joaquin Valley, associated with Temblor molluscan fossils, and it is actually repeated within shale streaks in the "Button bed" sandstone, in well sections. It seems probable, therefore, that this shale is Temblor in age.

If this condition is not recognized, it is obvious that a "*Valvulineria californica* assemblage," based on samples through the *Valvulineria californica* zone and the underlying shale (down to the top of the "Button bed" sandstone), might contain many species confined to the Temblor. This might well lead to a correlation of beds within the Temblor with the *Valvulineria californica* zone of the Monterey. Apparently Goudkoff has done this, as shown by his mention of a "*Valvulineria californica assemblage*" in his North Belridge section (see his table[2]) in beds here correlated as below the top of the "Button bed" (Table I).

Goudkoff states:

> The *Valvulineria californica* microfauna has not been found by the writer in samples obtained from these fields (Lost Hills and Kettleman Hills) (possibly because none of the studied wells was cored continuously). However, petrographic similarity of the sandstone in the three fields, the finding of no mega-fossils other than *Pecton andersoni*, and peculiarities in the brown shale just above the sandstone, indicate that the correlation of the North Belridge, Lost Hills, and Kettleman Hills sections is that shown in Table I.

The writers agree in the main with all these observations, differing only in regard to the correlation from the outcrop section to the adjacent North Belridge field, some minor points in the correlation between the three fields, and the conclusions which follow from Goudkoff's correlation in regard to the age of the producing horizon in North Belridge and Kettleman Hills.

Table I, herewith, is Goudkoff's Table I revised to show the correlation from type Temblor to North Belridge. It is evident that acceptance of this revised correlation, and of the rest of Goudkoff's observations stated above, leads to the conclusion that the oil horizon of Kettleman Hills consists of the Temblor formation of the type section.

Unfortunately, Eaton does not state the nature of the evidence obtained from his regional studies leading to his conclusion similar to that of Goudkoff

[1] A. R. May and J. D. Gilboe, "Foraminifera from the Type Section of the Temblor Formation, Carneros Creek Area, Kern County, California."

[2] Paul P. Goudkoff, *op. cit.*, p. 841.

that the oil-producing zone of Kettleman Hills is not Temblor in age, but is the overlying lower member of the Monterey. Hence, reply to Eaton's statement must be confined to a statement of conclusions from regional studies leading to a different opinion. The conclusions from regional studies indicating the producing horizon at Kettleman Hills to be the Temblor formation are as follows.

1. The presence of *Pecten andersoni* in the top part of the oil-producing zone at Kettleman Hills is believed to be significant in view of the widespread and plentiful occurrence of this fossil in the top part of the "Button bed" sandstone in the outcrops. *Pecten andersoni* has not been found in any part of the Monterey formation in the San Joaquin Valley.

2. The presence of *Scutella merriami* in the "Button bed" sandstone of the type Temblor and in the top of the Temblor sands in the Reef Ridge area outcrops, south of Kettleman Hills, and the similarity of the Kettleman Hills well sections to the latter outcrops, are considered to be evidence of the Temblor age of the producing zone of Kettleman Hills.

3. A mass of consistent evidence indicates that the Monterey formation has its maximum development in the San Joaquin Valley in the Chico-Martinez Creek and Carneros Creek areas and becomes thinner north and northwest by progressive overlap onto unnamed shale with Temblor affinities and older strata. This results in the absence of basal members of the Monterey (including the *Valvulineria californica* zone) in the Lost Hills and Kettleman Hills well sections and in the outcrops along Reef Ridge.

George M. Cunninhgam
W. F. Barbat

Bakersfield, California
February 29, 1932

CARRIER BEDS AND OIL ACCUMULATION

CORRECTION

In the March *Bulletin*, page 265, in the reply of John L. Rich to the discussion of W. V. Howard on Rich's papers on carrier beds and oil accumulation, an editorial error was made in the second sentence of the caption of Figure 1, by the omission of the words "none of the." The sentence should have read: "In either anticlines or salt domes all gradations may be expected from those where none of the fluids reaches the surface in the vicinity of the structures to those where all reach the surface as springs and seepages."

J. P. D. Hull

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 4 (APRIL, 1932), PP. 423-429

REVIEWS AND NEW PUBLICATIONS

Handbuch der Geophysik (Handbook of Geophysics). Edited by B. GUTENBERG. (Gebrüder Borntraeger, Berlin, 1931.) Band 1, Lieferung 1, 308 pp., 41 illus. 7 × 10½ inches. Price, 54 RM.; to subscribers to complete Handbook, 36 RM. Special to Association members, 25 per cent discount.

B. Gutenberg. Introduction: object of geophysics, the divisions of geophysics, the position of geophysics among the exact natural sciences, the results of geophysics. Pages 1-7.

F. Nölke. The development of the solar system and of the earth; the cosmic forces of evolution, the sun, the planets, the earth, the comets, and the zodiacal light, the earth in pre-geologic time. Pages 8-68.

M. Milankovitch. Position and movement of the earth in the universe: development of knowledge of the position and movement of the earth from the Chaldeans to Kepler; Kepler's laws and Newton's law of gravitation; the problem of two bodies in celestial mechanics; the problem of several bodies in celestial mechanics; the planetary system. Pages 69-138.

F. Hopfner. Figure of the earth, density and pressure in the subsurface: review of the development of the knowledge of the form of the earth to a time within the second half of the 19th century; the form of the earth as a geometric problem; the form of the earth as a physical problem. Brun's mathematical-physical theory of the form of the earth; digest of some methods of measurement and reduction in higher geodesy; geodetic methods of determination of ellipsoidal surfaces of reference; density, pressure, and gravity in the interior of the earth.

The volume is a monumental scholarly work, but in general it will be outside of the field of interest of petroleum geologists and geophysicists except perhaps of one or two geologists who may become interested in the abstrusely fundamental geologic problems of the origin of the earth or the geophysics of its interior, or of a rare petroleum geophysicist who may become interested in the pure geophysics of the earth. Nölke does not accept Chamberlin and Moulton's planetesimal hypothesis. The whole massive *Handbuch* of which this is one volume should be included in the reference library of geophysical departments doing very advanced research and possibly also of geologic departments which maintain the most complete libraries. The present volume need not be included in the library of an oil company or average university geologic or geophysical department.

DONALD C. BARTON

HOUSTON, TEXAS
February 17, 1932

Das Erdöl in Deutschland. By FRED S. BAUMANN. (Carl Heymanns Verlag, Berlin, 1930.) 76 pp. Price, RM. 10.

This little book gives a comprehensive and informative account of geology, development, and economics of the German oil fields and industries. From the introduction we gather all the important facts concerning the increasing consumption of refinery products, the use of motors in Germany, imports, exports, et cetera. In the following parts there are chapters on the development of German deep drilling and oil producing enterprises (from the first "oil boom" at Ölheim about 50 years ago to the arrival of American companies since 1929). The book contains graphs on development of production from 1880 to 1929 in the three main districts (Wietze, Nienhagen, and Oberg Ölheim), paragraphs on the general geologic setting of the northwest German oil region, the present refinery capacity, the qualities of German crude oils, the Bavarian and Rheingraben oil regions, the protective tariff measures against foreign imports, and principal laws concerning oil exploration and exploitation in Germany.

The history of the districts is very interestingly pictured from the geologic and economic point of view. Excellent topographic maps and several cross sections make it easy to follow the descriptions. Unfortunately, the Thuringian oil development of Volkenroda is not mentioned, as oil in commercial amounts was discovered there only late in 1930. A new edition of the book is in preparation and the Thuringian oil developments are to be described there.

In the appendix we find dependable information about the oil companies, their wells drilled and producing (in 1928), boards of directors and "Aufsichtsraete" of the major companies; furthermore, reprints of the laws and administrative measures controlling the oil business in all its stages. This book is written in a very readable style of German, and the type is excellent.

RUDOLF F. VON ZWERGER

BERLIN-ZEHLENDORF
February 6, 1932

General Report and Review, West Texas District, to December 31, 1931. Prepared by oil company scouts in the West Texas district, for company information. 49 mimeog. pp.

This is a statistical review of operations in West Texas where there are 26 producing fields. During the year, 78,610,700 barrels were produced, as compared with 109,016,700 barrels during 1930. More than 5,000,000 barrels were withdrawn from storage. During the first eight months, more than 1,200,000 acres of leasehold was cancelled by twenty-three major operating companies, representing 13 per cent of the total acreage held by them. In the Big Lake field, Reagan County, discovered in May, 1923, there are 242 wells producing from the Permian from depths ranging from 2,400 to 3,000 feet, all of which are showing water, and the yield to date has been 14,900 barrels per acre for 3,390 acres. There are 9 producing wells in the Arbuckle formation of Ordovician age at a depth of more than 8,500 feet, which have produced more than 9,000,000 barrels since December, 1928. One of these

wells produced 9,500 barrels a day with 65,000,000 cubic feet of gas, and almost all of the gas produced is wasted.

SIDNEY POWERS

TULSA, OKLAHOMA
March, 1932

"The Milk River Area and the Red Coulee Oil Field, Alberta (Canada)." By C. S. EVANS. *Geol. Survey of Canada Summary Rept. 1930*, Pt. B (1932). 30 pp.

Oil is produced from the Vanalta oil sand in the Kootenay series of Lower Cretaceous age on a nose plunging northwestward from the northwest flank of the Sweetgrass arch of Montana. Sand conditions in this area are lenticular.

SIDNEY POWERS

TULSA, OKLAHOMA
March, 1932

"Gas in the Tioga Region, Pennsylvania." By G. H. ASHLEY and S. H. CATHCART. *Pennsylvania Topog. and Geol. Survey Bull. 102 A* (Harrisburg, January, 1932). 13 mimeographed pp., 2 folded maps showing structural axes and well locations.

This bulletin, revised and reissued as developments warrant, reviews developments in the Tioga gas field, discovered in September, 1930, the new Potter County (Hebron) gas field, discovered on October 20, 1931, and elsewhere. At the time of writing there were 26 gas wells and 36 failures (in most wells salt water was found, in others neither gas nor water) in the Tioga field, one gas well in the new field, 35 miles west (7 miles north of Coudersport). The gas is produced from the Oriskany sand of Lower Devonian age.

SIDNEY POWERS

TULSA, OKLAHOMA
February 26, 1932

"Geology of Iberia Parish (Louisiana)." By H. V. HOWE and C. K. MORESI. *Louisiana State Conservation Commission Bur. Sci. Research Min. Div. Geological Bull. 1, November, 1931* (New Orleans, Louisiana, 1932). 187 pp., 18 figs., 3 photographs. 6 × 9 inches. Paper. Free.

This book of 187 pages includes 41 pages of references with 224 titles. The discussion of the surface geology is complete. No changes in elevation of the Five Island salt domes or of the surrounding area took place between 1905, when bench marks were established by G. D. Harris, and 1918, when they were re-run by the U. S. Coast and Geodetic Survey.

SIDNEY POWERS

TULSA, OKLAHOMA
February 26, 1932

"Petroleum Geology of the State of São Paulo, Brazil." By CHESTER W. WASHBURNE. *Commissão Geographica e Geologica do Estado de São Paulo Bol. 22* (São Paulo, Brazil, 1930). 282 pp., 121 figs., 10 sketches, 3 maps, including a geological map of the state in colors. Approx. 6¼ × 9⅛ inches.

A comprehensive report on the geology and petroleum possibilities of the State of São Paulo in southeastern Brazil, evidently prepared not only for the Geological Commission of São Paulo, but also for such oil companies as might become interested in investigating the petroleum possibilities of the state. It contains discussions of the climate, physiography, drilling conditions, transportation problems, and oil rights of the state, and makes recommendations to the Brazilian Government for liberality in concessions granted to foreign oil companies. The main body of the report is a detailed description of the stratigraphy of the region—a part of the Paranâ Basin— of the structure of certain anticlines, "structure at waterfalls" (gentle folds in the basalt flows, due to original topographic features over which the basalt flowed), and of faults (with an interesting aside on evidences against the theory of continental drift) In his recommendations, the author, with refreshing candor, states that the anticlines described are sufficient for the needs of the state and that further prospecting should be left to private enterprise, and oil companies be given a free hand to acquire attractive territory without having to deal with lease brokers. The author indulges in speculations regarding the source beds, date of origin of the oil, its method of accumulation, and the reservoir rocks. He concludes that the Devonian and Permian (Iraty beds) are the source rocks, that the date of origin was late Triassic or early Jurassic, and that the flushing action of "currents of water" caused accumulation in anticlines down dip. A section of the report is devoted to a discussion of the wells drilled in the state with their logs, and the statement is made that, although none of them was located on a favorable anticline or was drilled to sufficient depth, their showings and the discovery of natural gas contradict the statement of I. C. White (1906), "The probabilities are all against the discovery of petroleum in commercial quantities in Brazil." In a summary of conclusions placed as an introduction to the report, Washburne states that the region is sufficiently attractive to justify further prospecting, especially in the southwestern part of the state where the Devonian (the source beds of eastern Bolivian oil, 500 miles west of the Paranâ Basin) is supposed to exist and where the most favorable "structures" do exist despite the necessity of drilling through a capping basalt of unknown thickness. Tests 4,500 feet deep are recommended.

The report is well illustrated with maps, sketches, and many photographs. It contains a 21-page bibliography and as a supplement a brief report on the geology of Paranâ.

HELEN M. MARTIN

TULSA, OKLAHOMA
March 15, 1932

"The Chemistry of the Conversion of Algae into Bitumen and Petroleum and of the Fucosite-Petroleum Cycle." By J. E. HACKFORD. *The Journal of The Institution of Petroleum Technologists*, Vol. XVIII, No. 100 (London, February, 1932), pp. 74-123.

This is a paper read at the annual meeting of The Institution of Petroleum Technologists, London, in which Mr. Hackford presents a discussion of his experiments on algae and on oil seepage, by which he seeks to prove that petroleum and some bitumens were derived mainly from sugars produced as the result of acid hydrolysis of algae. The theory is supported by the facts that oil was produced experimentally from algae by processes that are similar to those obtained in nature; that oil from wells and seepages (California) contains the decomposition products of algae; and that the experiments were checked by reconversion of oils and oil seepages into bodies resembling or identical with the decomposition products of algae and into bitumens which on hydrolysis yielded sugars. A further supporting evidence is in the similarity of the mineral and chemical constituents of algae and petroleum. A suggestion is made that oil-forming substances of algae migrated in solution with underground water and "decomposed at leisure in some geologic trap on the original site of deposition or at some distance therefrom" and that algerite—the McKitterite, kerogen-like bitumen—and calcium sulphate might have been deposited and oil produced simultaneously along the path of travel or in the trap, or the algerite and sulphate might have been precipitated first and decomposition to oils have occurred later, and at another place. The theory is plausible and well supported by experimental evidence, and has fewer objections against it than other theories that attempt to explain the origin of oil.

HELEN M. MARTIN

TULSA, OKLAHOMA
March 15, 1932

"Geophysical Prospecting, 1932." *Trans. Amer. Inst. Min. Met. Eng.* (New York, 1932). Papers presented before the institute at the New York meetings in February, 1929, 1930, 1931, and 1932. 509 pp. 6¼ × 9¼ inches.

"Geophysical Prospecting, 1929," published by the American Institute of Mining and Metallurgical Engineers, has been recognized as one of the most important publications on geophysics. "Geophysical Prospecting, 1932," is a fitting companion and sequel.

The present volume is a compilation of twenty-seven papers dealing with the four best known methods of geophysical exploration, namely, electrical, magnetic, seismic, and gravimetric. The first two papers are of a general nature, discussions of choice of methods, experience, and results. These are followed by nine papers on electrical methods, seven of which deal with resistivity and two with electromagnetic methods. There are three papers on magnetic methods, three on seismic, instrument, and refraction work, two on the interpretation of gravitational anomalies, and five theoretical studies of which four are devoted entirely to electrical prospecting.

It is to be regretted that it has not been possible to include papers on seismic reflection surveys, the geophysical method of greatest interest to the petroleum geologist at the moment.

As the papers were written and discussed by men who are prominent in their respective fields, the book constitutes an important contribution to the literature.

ANDREW GILMOUR

TULSA, OKLAHOMA
March 15, 1932

RECENT PUBLICATIONS

CANADA

"Stratigraphy and Structural Geology of the Moose River Basin, Northern Ontario," by W. S. Dyer. *Trans. Roy. Soc. Canada* (Ottawa), 3rd Ser., Vol. 25, Sec. 4 (1931), pp. 85-99; 3 figs.

COLOMBIA

"Ein Profil durch den Chocó-Westhang der West-Kordillere in Kolumbien (Südamerika)" (A Profile through the Chocó Western Slope of the Western Cordillera in Colombia), by Karl Ermisch. *Zeits. f. prak. Geol.* (Halle, Saale, Germany, February, 1932), pp. 17-21; 2 figs.

GENERAL

"Bibliography of North American Geology, 1929 and 1930," by J. M. Nickles. *U. S. Geol. Survey Bull. 834* (Supt. Documents, Washington, D. C.), ii + 280 pp. Price, $0.45.

Oil Economics, by Campbell Osborn. Application of economic facts and principles to problem of management and investment in petroleum industry (McGraw-Hill Book Company, Inc., New York, 1932). 402 pp., 32 figs., including appendix with 49 tables and bibliography. 6 × 9¼ inches. Cloth. Price, $4.00.

Das Erdöl (Petroleum), by C. Engler and H. Höfer. 2nd ed. Edited by J. Tausz. Vol. 3, Pt. 1, *Gewinnung des Erdöls* (Production of Petroleum) contains "Gewinnung des Erdöls durch Bohren" (Production of Petroleum by Drilling), by K. Glinz, and "Gewinnung des Erdöls durch Schachtbau" (Production of Petroleum by Mining), by G. Schneiders. (S. Hirzel, Leipzig, Germany, 1932.) xii + 262 pp., 202 figs., 4 tables. Lexikon-Format Boschiert, RM. 38; Leinen, RM. 40.

"Einige Betrachtungen über die Migration des Erdöls" (Observations on Migration of Petroleum), by A. F. von Stahl. *Petrol. Zeits.*, Vol. 28, No. 1 (Berlin, January 6, 1932), pp. 7-8.

"The Mechanics of the Plains-Type Folds of the Mid-Continent Area," by Stuart K. Clark. *Jour. Geol.* (Chicago), Vol. 40, No. 1 (January-February, 1932), pp. 46-61, 10 figs.

GEOPHYSICS

Handbuch der Geophysik (Handbook of Geophysics), Band 1, Lieferung 1 (1931), edited by B. Gutenberg. Contains "Einleitung: Allgemeines über

Geophysik" (Introduction to General Geophysics), by B. Gutenberg; "Die Entwicklung des Sonnensystems und der Erde" (Development of the Solar System and the Earth), by F. Nölke; "Stellung und Bewegung der Erder in Weltall" (Position and Movement of the Earth in the Universe), by M. Milankovitch; "Figur der Erde, Dichte und Druck in Erdinner" (Form of the Earth, Its Density and Interior Pressure), by F. Hopfner. (Gebrüder Borntraeger, Berlin.) 308 pp., 41 illus. Price, 54 RM.; to subscribers to complete Handbook, 36 RM. Special to Association members, 25 per cent discount.

"Electrical Coring; A Method of Determining Bottom-Hole Data by Electrical Measurements," by C. and M. Schlumberger and E. G. Leonardon. *Amer. Inst. Min. Met. Eng. Tech. Pub. 462* (New York, 1932). 38 pp., 22 figs.

GERMANY

"Zur Entstehung der hannoverschen Erdöllagerstätten" (The Origin of the Hannover Petroleum Deposits), by A. Bentz. *Intern. Zeits. f. Bohr. Erdölb. u. Geol.* (Vienna), Vol. 40, No. 3 (February 1, 1932), pp. 19-26.

GREECE

"The Geology of Zante and Its Ancient Oilfield," by Arthur Wade. *Jour. Inst. Petrol. Tech.* (London), Vol. 18, No. 99 (January, 1932), pp. 1-36; 3 figs., 2 pls., 9 photographs.

NEW YORK

"Recent Natural Gas Developments in South-Central New York," by D. H. Newland and C. A. Hartnagel. *New York State Mus. Cir. 7* (Albany, February, 1932). 20 pp., illus.

PENNSYLVANIA

"Gas in the Tioga Region, Pennsylvania," by George H. Ashley and Stanley H. Cathcart. *Pennsylvania Topog. Geol. Survey Bull. 102A* (Harrisburg, January, 1932). 13 mimeog. pp.; 2 maps, one showing anticlinal axes in northeastern Pennsylvania. Part B of this report, containing more detailed geologic data, may be obtained for postage, $0.06.

TEXAS

"Anhydrite and Associated Inclusions in the Permian Limestones of West Texas," by John Emery Adams. *Jour. Geol.* (Chicago), Vol. 40, No. 1 (January-February, 1932), pp. 30-45; 2 figs.

WASHINGTON

"A Miocene Flora from Grand Coulee, Washington," by E. W. Berry. *U. S. Geol. Survey Prof. Paper 170-C* (Supt. Documents, Washington, D. C.), pp. i-ii, 31-42, Pls. 11-13, Fig. 3. Price, $0.10.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 4 (APRIL, 1932), PP. 431-433

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

William Horace Butt, Caibarien, Cuba
Roy E. Dickerson, William D. Chawner, H. V. Tygrett
Don Philip Coleman, Wichita, Kan.
R. J. Riggs, R. C. Moore, R. S. Knappen
George Porter Hardison, Tulsa, Okla.
Sherwood Buckstaff, E. S. Pratt, W. C. Bean
Gilbert Charles McAuliffe, Monroe, La.
Victor Cotner, Henry V. Howe, Preston Fergus
Benjamin Martin Shaub, Northampton, Mass.
J. R. Reeves, H. Ries, C. M. Nevin

FOR ASSOCIATE MEMBERSHIP

Hugh Reno Brankstone, Pittsburgh, Pa.
R. E. Somers, K. C. Heald, R. W. Clark
Robert Curtis Briggs, San Antonio, Tex.
S. A. Thompson, B. Coleman Renick, Guy E. Green
Cleo Wyatt Eckenwiler, Tulsa, Okla.
Harry H. Nowlan, George I. McFerron, C. J. Stafford
George William Mechling, Lincoln, Nebr.
E. F. Schramm, A. L. Lugn, E. C. Reed

FOR TRANSFER TO ACTIVE MEMBERSHIP

Donald E. Fuellhart, Natchitoches, La.
C. M. Dorchester, H. Harper McKee, Dugald Gordon

SAN ANTONIO SECTION ANNUAL MEETING

The annual meeting of the San Antonio Section of the Association was held on Saturday, February 27, at the Plaza Hotel, Corpus Christi, Texas, after a field trip on the preceding day, which began at San Antonio and extended through Three Rivers, George West, Alice, and Agua Dulce, ending at night with a sea-food dinner on the Deck of the Plaza at Corpus Christi.

The newly elected officers of the section are: president, Edgar W. Owen, representative for the Wentz Oil Corporation in San Antonio; vice-president, Olin G. Bell, district geologist for the Humble Oil and Refining Company, Laredo; secretary-treasurer, Charles A. Stewart, district geologist for the United Production Corporation, San Antonio; member of the executive committee, Thornton Davis, manager for the Simms Oil Company, San Antonio. The Section has a membership enrollment of 119.

The technical program, including the following papers, was attended by nearly 200 persons.

"The Goliad Sandstone Formation of Southwest Texas," by I. K. Howeth and Phillip F. Martyn

"The Reynosa, Upland Terrace, and Lissie Deposits of the Coastal Plain of Texas between the Brazos River and Rio Grande," by A. W. Weeks

"The Oakville, Lagarto, and Reynosa Stratigraphy between the Nueces and Guadalupe Rivers," by E. L. Johnson

"The Reynosa Problem," by W. Armstrong Price

"A General Discussion of Recent Development from McMullen to Austin County with Particular Reference to the Jackson Series of the Tertiary System," by R. C. Bowles

"Criteria of Faulting in the Pettus Area," by Rual B. Swiger

"A Resumé of the Laredo District for the Past Two Years," by Guy B. Gierhart

"The Concho Divide," by M. G. Cheney

"Remarks on Correlation Problems of the Pre-Pennsylvanian in the Central Mineral Region," by Hedwig T. Kniker

"The Lower Claiborne on the Brazos River, Texas," by B. Coleman Renick

"A Study of the Wildcat Oil Field Ratio and the Per Barrel Discovery Cost of Oil in the San Antonio Fault Country," by Frank C. Adams

"Some Notes on the Marine Wilcox," by F. W. Rolshausen

ASSOCIATION COMMITTEES

EXECUTIVE COMMITTEE

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William B. Heroy, *secretary*, Sinclair Exploration Company, New York, N. Y.
Lovic P. Garrett, Gulf Production Company, Houston, Texas
Robert J. Riggs, Indian Ter. Illum. Oil Company, Bartlesville, Oklahoma
R. D. Reed, The Texas Company, Los Angeles, California

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David Donoghue (1932), *vice-chairman*, 1116 Fort Worth Natl. Bank Building, Fort Worth, Texas

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L. Courtney Decius (1932)
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L. G. Huntley (1933)
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Ed. W. Owen (1933)
Sidney Powers (1932)
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A. H. Richards (1933)
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R. C. Moore (1933)
Sidney Powers (1934)

GEOLOGIC NAMES AND CORRELATIONS

A. I. Levorsen, *chairman*, 1740 South St. Louis Avenue, Tulsa, Oklahoma

M. G. Cheney
Ira H. Cram
B. F. Hake
G. D. Hanna
C. L. Moody
R. C. Moore

TRUSTEES OF REVOLVING PUBLICATION FUND

E. DeGolyer (1934)
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R. D. Reed (1932)

TRUSTEES OF RESEARCH FUND

W. E. Wrather (1934)
T. S. Harrison (1933)
Alex. W. McCoy (1932)

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 4 (APRIL, 1932), PP. 435-436

Memorial

THOMAS HARTMAN OLDS

Thomas Hartman Olds died at his home in Denver, Colorado, on February 10, 1932, from a heart attack, having been confined to his home for two months. This sad news is a shock to his many friends and acquaintances who find difficulty in realizing that such an active, ambitious man will not be with them again.

He was born in Pontiac, Illinois, November 25, 1883. While a boy he lived for some time in Mexico, with his father, who was busy with construction work and the sale of machinery. From 1898 to 1902 he attended Texas Agricultural and Mechanical College, and after graduation as Bachelor of Science, responded to the call of Mexico and worked as civil engineer on railroad, power plant, and other construction work. As this developed a desire for further study, he entered Cornell University in September, 1905, and in June, 1907, received the degree of Civil Engineer. His enthusiasm and desire to see the culmination of certain construction work in Mexico kept him there until December, 1910, when he went farther south and remained until June, 1914, as principal assistant engineer on hydro-electric power plants in the state of São Paulo, Brazil, for the São Paulo Electric Power Company.

After such a long separation from his father, a fitting demonstration of affection was the association of father and son in the design and sale of machinery in Denver, Colorado, from October, 1914, to November, 1916. Those who knew them both and observed this companionship will cherish a pleasant recollection. From 1916 to 1918 he was deeply absorbed in water supply and hydro-electric engineering in the Rocky Mountain region. He showed his love of country by voluntary enlistment for the World War, but numerous technicalities about medical examination, et cetera, delayed his acceptance until the time of the armistice.

Late in 1918 he became associated with the firm of Fisher and Lowrie, consulting geologists and engineers, of Denver. He specialized along the lines of oil production, estimation of reserves, rate of decline, depletion, and valuation, and the relation of geology thereto, maintaining this association until 1929. It is noteworthy that in conjunction with W. B. Case, in August, 1921, he made one of the first maps prepared by private parties, showing the structural condition between Salt Creek and Teapot domes. In 1929, he accepted a position as geologist, engineer, and appraiser, with the Midwest Oil, Saltmount, and associated companies, continuing increasingly active in this capacity until his untimely death.

Tom Olds was a member of the American Society of Civil Engineers and the Colorado Society of Engineers. He was one of the early members of the Rocky Mountain Association of Petroleum Geologists and for several years represented the latter as delegate to the Colorado Engineering Council. He

was elected to associate membership in The American Association of Petroleum Geologists, February 16, 1927. He has left a noteworthy professional record of accomplishment in the application of engineering to geology and oil production and valuation, and an equally fine human record of his attainment along social, civic, public welfare, and allied lines. He will be remembered not alone as an engineer and geologist, but as an all-round citizen. Always busy and overworked, he was never too busy for a short interview and a few kind words of advice or information, always interested in people and their problems, winning the lasting friendship of all who knew him.

On January 4, 1922, Tom married Miss Gertrude Bunger, who survives him, as does his son Robert, aged four. His brother, Fred H. Olds, resides at Colorado Springs, Colorado. His good companion, his father, died in October, 1931. There are no other immediate relatives.

CHARLES M. RATH

DENVER, COLORADO
March 12, 1932

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 4 (APRIL, 1932), PP. 437-442

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

HUGH MCCLELLAN announces the opening of an office for consulting geology at 120 E. Sixth Avenue, Hutchinson, Kansas.

HAROLD T. MORLEY, formerly division manager of the exploration department for the Stanolind Oil and Gas Company in Texas, is now chief geologist for the same company in Tulsa.

JOSEPH HORNBERGER, JR., has been appointed assistant geologist for the Bureau of Economic Geology, University of Texas, Austin.

PAUL M. PHILLIPPI, formerly with the Nebraska Department of Public Works, Lincoln, is now with Torrey, Fralich, and Simmons Company, Bradford, Pennsylvania.

O. L. BRACE, geologist for E. L. Smith Oil Company, Tyler, Texas, has a paper "East Texas Well Cores Tell Story," in the February 18 issue of *The Oil and Gas Journal.*

EMIL KLUTH, of the George F. Getty Company, has been elected vice-president of the Pacific Western Oil Company.

H. E. ZOLLER, of the Shell Petroleum Corporation, formerly located at Kilgore, Texas, has been sent to Holland to do several months' exploration work for the company.

J. WHITNEY LEWIS, consulting geologist of Havana, Cuba, has returned to the States and is living at 5823 Monticello Avenue, Dallas, Texas.

E. E. ROSAIRE, of Houston, Texas, has resigned from the Geophysical Research Corporation to engage in geophysical work for himself.

IRA M. HICKS, of the Amerada Petroleum Corporation, at San Angelo, Texas, has had a very severe illness from which he is slowly recuperating.

The Geological Survey of Kentucky has been temporarily discontinued. This department of the state has now been placed under the supervision of the University of Kentucky at Lexington.

T. W. STANTON has been appointed chief geologist of the United States Geological Survey.

DAVID WHITE, of the United States Geological Survey, has recovered from a prolonged illness and is working at the National Museum.

RALPH RICHARDS, of the United States Geological Survey, has returned to Washington after making a study of the underground structure of the Kettleman Hills field, California.

CHARLES E. STRAUB, consulting geologist, has moved from Wichita, Kansas, to 618 Fuhrman Avenue, Bellevue, Kentucky.

G. L. ELLIS, consulting geologist, is living at 436 Forty-Ninth Street, Philadelphia, Pennsylvania.

A. F. CRIDER, consulting geologist, of Shreveport, Louisiana, is working in western Kentucky.

W. T. THOM, JR., of Princeton University, has given a course of lectures at Rice Institute, Houston.

Because of the date of the International Geological Congress at Washington in 1933, the Third International Drilling Congress will be held at Berlin in 1934, probably in September. The German National Committee will issue a Year-Book containing papers on geology, geophysics, drilling technique, mining regulations, et cetera.

R. BRAUCHLI, geologist for the Anderson-Pritchard Oil Corporation, Oklahoma City, addressed the Tulsa Geological Society, Monday, March 7, on "Coring in the Oklahoma City Field." L. L. FOLEY also addressed the Society on "Tectonics of the Oklahoma City Structure."

At the regular meeting of the West Texas Geological Society, February 27, at San Angelo, Texas, P. D. MOORE addressed the Society on "The Geology of the Turner Valley Field, Alberta."

STANLEY C. HEROLD is the author of an article entitled "Recent Progress and Present Tendencies in American Petroleum Technique" in the March issue of *American Engineering and Industry*, the technical monthly magazine of the Amtorg Publishing Division, New York.

ANGUS MCLEOD, manager of geological operations for Shell Petroleum Corporation in the Southern district, comprising Texas, New Mexico, Louisiana, and Arkansas, with headquarters at Dallas, Texas, was elected chairman of the Dallas Petroleum Geologists on February 16. Mr. McLeod succeeds R. B. WHITEHEAD. L. W. ORYNSKI, district geologist for the California Company, was elected vice-chairman, and SAM M. ARONSON, geologist for the Atlantic Oil Producing Company, was retained as secretary.

H. J. DUNCAN, Muskogee, Oklahoma, has been appointed supervisor of the mineral leasing division of the United States Geological Survey, Casper, Wyoming, to succeed HALE B. SOYSTER, who was recently promoted and sent to Washington.

J. W. STEELE, formerly supervisor of the mineral leasing division, United States Geological Survey, who has until recently been in charge of the Sinclair interest explorations in Portuguese West Africa, has re-entered the service

and has been appointed deputy supervisor of the mineral leasing division of the survey at Roswell, New Mexico.

CHESTER NARAMORE, general manager of the North European Oil Corporation, Hannover, Germany, is in New York City at the present time.

JAMES D. WHEELER is employed by the Mid-Kansas Oil and Gas Company as petroleum engineer at Henderson, Texas.

L. L. FOLEY is in charge of petroleum engineering for the Mid-Kansas Oil and Gas Company, Tulsa, Oklahoma.

The 9th International Congress of Chemistry will not be held in 1932. It will be held at Madrid at a later date.

The San Antonio Geological Society, a section of the Association, has presented the following program at regular monthly meetings at San Antonio, Texas, since November, 1931: "Oil Imports and Exports in the United States," by H. J. STRUTH of the *Oil Weekly;* "Some Physiographic Features of the High Plains," by R. B. CAMPBELL, consulting geologist of San Antonio; "Nomenclature of the Oil and Gas Fields of Southwest Texas," by a special committee; "Through the Oil Fields of Mexico," and "Through the Oil Fields of Europe and Africa with Special Reference to Italy, the Danube, Hungary, and Roumania," both motion pictures.

HAL P. BYBEE, of the Board for Lease of University Lands, San Angelo, Texas, addressed the Fort Worth Geological Society at Texas Christian University, March 5, on "Deep Production in the Big Lake Oil Field."

Mrs. Carl F. Theisen, née BETH WORTHINGTON, is now residing at 420 Memorial Drive, Cambridge, Massachusetts.

E. RUSSELL LLOYD, assisted by E. HAZEN WOODS, has opened an office for the Superior Oil Company of California in the Hogan Building at Midland, Texas.

CHESTER W. WASHBURNE, consulting geologist of 41 Emerson Avenue, New Rochelle, New York, is in Oregon on professional business.

WILLIS STORM, geologist, has moved from Dallas to 2146 West Summit Avenue, San Antonio, Texas.

RAMSAY MACDONALD, last February, opened the Institute of Geology and the Institute of Engineering, which are extensions of the University of Edinburgh. The Institute of Geology was dedicated to the memory of Hugh Miller, one of the early pioneers in geology.

H. M. Horton is in charge of the geological work in Texas for the Superior Oil Company of California with headquarters in Dallas.

JOHN TEAGLE, of the Humble Oil and Refining Company, is taking graduate work at the University of Texas.

A. G. MADDREN, consulting geologist, is working in Dallas.

JOHN W. CLARK, of the Magnolia Petroleum Company, has been transferred to Oklahoma City.

HENRY C. CORTES, of the Magnolia Petroleum Company, is in charge of geological work at Lake Charles, Louisiana.

BRUCE WHITCOMB, formerly of Cosden Oil Company, is now living in Corsicana, where he is studying shallow gas prospects.

JOE PALMER is living in Laredo, Texas.

J. M. MUIR is geologist for the Rio Oil Company of Fort Worth, Texas.

EARL A. TRAGER, of Tulsa, Oklahoma, and Miss MARTELLE WICKLIFFE of Chillicothe, Texas, were married on March 12, 1932. Trager is with the research and educational department of the National Park Board at Washington, D. C.

HANS STILLE, professor at the Geological Institute, Göttingen, will spend the summer in Montana with the International Summer School of Geology and Natural Resources of Princeton University. W. T. THOM, JR., of the Princeton faculty, will have charge of the school.

K. C. HEALD, of the Gulf Companies, Pittsburgh, is in South America on an inspection trip.

WILLIAM J. MILLARD, consulting geologist, has his office at the Engineers Club, 23 West Fortieth Street, New York City.

W. D. MILLER, vice-president of the Esperanza Petroleum Corporation of New York City, is in Venezuela.

M. G. CHENEY discussed "East Texas Paleogeography and Oil Migration," before the Dallas Petroleum Geologists, March 17, at Dallas, Texas.

WALKER S. CLUTE, who has been in charge of the Tulsa, Oklahoma, office of the United States Geological Survey during the past year, is transferring his activities to his former field of operations, having been appointed petroleum engineer of the Tax Research Bureau, California State Board of Equalization, at Sacramento.

W. P. HASEMAN, formerly of the research department of the Marland Oil Company and of the faculties of Indiana University and the University of Oklahoma, died at Oklahoma City on March 14.

W. P. JENNY, Magnolia Petroleum Company, Dallas, Texas, has an article "New Calculation Method Shows Ultimate East Texas Yield" in the March 11 issue of *The Oil Weekly*.

ROBERT N. KOLM should be addressed Apartado 10, Matanzas, Cuba, instead of Apartado 100 as shown in the membership list published in the March, 1932, *Bulletin*.

H. C. GEORGE, director of the School of Petroleum Engineering at the University of Oklahoma, Norman, Oklahoma, announces a summer field course in the petroleum industry, June 9 to August 5, 1932.

R. C. PATTERSON, supervisor of oil and gas operations for the U. S. Geological Survey in California, addressed a joint meeting of the Tulsa Geological Society and the Mid-Continent section of the American Institute of Mining and Metallurgical Engineers March 21, on "Kettleman Hills North Dome."

H. D. EASTON, consulting geologist of Shreveport, Louisiana, has an article in the *Oil and Gas Journal* of March 24, entitled "Glen Rose Possibilities in Zwolle Area."

EDWARD BLOESCH, consulting geologist of Tulsa, Oklahoma, writes on "Overproduction?" in the *Royalty Age* of March.

ALBERT W. GILES, professor of geology of the University of Arkansas, has published an article, "Textural Features of the Ordovician Sandstones of Arkansas," in the February-March *Journal of Geology*.

D. G. BARNETT has moved from Laredo to Houston, Texas, where he is in the geological department of the United Production Corporation.

JEAN O. NELSON is superintendent of the East Texas division in the production department of the Lion Oil Refining Company of El Dorado, Arkansas. He is stationed at Henderson, Texas.

A. M. GAUDIN, chairman of the graduate committee of the Montana School of Mines, Butte, Montana, in coöperation with the State Bureau of Mines and Geology, announces the availability of research fellowships in geology and mining, carrying stipends of $750.00 each for a period of ten months beginning September 1, 1932.

JOSEPH A. CUSHMAN and P. W. JARVIS, of the Cushman Laboratory, Sharon, Massachusetts, are the authors of "Upper Cretaceous Foraminifera from Trinidad," which is publication 2914 of the *Proceedings of the U. S. National Museum*.

The West Texas Geological Society will hold an annual field trip, May 14 and 15, to the Solitario uplift in Presidio County. Information may be obtained from the secretary, San Angelo, Texas.

At a meeting of the West Texas Geological Society, March 19, at Midland, Texas, CHARLES LAURENCE BAKER spoke on "The History of the Rio Grande."

RAY R. MOODY, geologist for the Gypsy Oil Company, and formerly located at Wichita, Kansas, has been transferred to the Rocky Mountain district and may be addressed at Box 2097, Denver, Colorado.

CHESTER D. WHORTON, formerly of San Antonio, Texas, announces the opening of offices in Coudersport, Pennsylvania, which is in the center of the new Pennsylvania and New York gas area.

ARNOLD S. BUNTE is now consulting geologist for C. B. Bunte, Inc., 1225 Majestic Building, San Antonio, Texas.

W. E. HUBBARD, of the Humble Oil and Refining Company, has been transferred from Amarillo to be district superintendent at McCamey, Texas.

FRANK A. HERALD, geologist and petroleum engineer, is situated at 2105 Fort Worth National Bank Building, Fort Worth, Texas. Mr. Herald was general manager of the Westbrook-Thompson Holding Corporation from 1929 to 1932.

President Lowell, of Harvard University, has announced a new research project in geophysics financed by a grant of $50,000 from the Rockefeller Foundation and $50,000 to be raised by Harvard. The investigation is to be conducted over a period of five years to study the elastic properties of rocks. The committee in charge consists of Professors R. A. Daly, L. C. Graton, and D. H. McLaughlin, geologists; Harlow Shapley, astronomer; and P. W. Bridgman, physicist.

GEORGE C. BRANNER, state geologist of Arkansas, gave his presentation of historical geology by means of animated maps with special reference to the Mid-Continent area, before the Tulsa Geological Society, April 4, 1932.

An employment council composed of representatives from the Tulsa Geological Society and the local sections of the national engineering societies has been organized to act as a clearing house in the unemployment situation among geologists and engineers in Oklahoma and adjacent areas. The representatives of the Tulsa Geological Society are Robert H. Dott, president of the Society, J. P. D. Hull, and W. F. Lowe. All inquiries should be sent to Box 1852, Tulsa, Oklahoma.

H. W. C. PROMMEL, consulting geologist of Denver, Colorado, has returned after working on non-ferrous ore deposits in Russia.

ADDISON YOUNG, geologist of Dallas, Texas, has an article, "Ordovician Production May Be Next Major Texas Development," in the *Oil Weekly* of April 4.

GEORGE E. BURTON, geologist of Ardmore, Oklahoma, has opened a consulting office at 304 Construction Building, Dallas, Texas.

H. RIES and G. D. CONANT, of Cornell University, Ithaca, New York, are the authors of a paper "The Character of Sand Grains," published by the American Foundrymen's Association in 1931.